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ORIGINAL ARTICLES.

The Petrography and Correlation of the Igneous Rocks of the Torquay Promontory

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(PLATE IX.)

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I. Introduction.

THE district to which this paper refers lies mainly to the east of the Upton and Fleet Valleys in Torquay: to the west of this line there are large areas of unconformable Permian rocks, to the east the Permian is absent, except in the neighbourhood of Babbacombe, where to the north the extensive deposits of this age are to be seen stretching as far as the estuary of the Exe, broken only by the Upper Devonian of Petit Tor.

The succession is from the Lower Devonian Meadfoot Beds to the Upper Devonian slates. The scope of the paper is the correlation of the igneous rocks and their evidence as regards the tectonic features. A full discussion of the tectonics cannot be undertaken until the limestones have been correlated.

The earliest workers in the area were De la Beche and Godwin-Austen. The former, in his *Geological Manual*, figures the section at Black Head. In 1903 was published the Survey Memoir on the district, by the late W. A. E. Ussher (1),[1] but the igneous rocks had slight consideration.

Previous workers have concerned themselves with the general

[1] Figures in parentheses refer to Bibliography at end of paper.

stratigraphic succession and with the search for fossils. The latter are somewhat rare, and generally in bad preservation; there seems to be little hope of working out the tectonics by their aid alone.

II. The Field Evidence and General Geology.

There is no direct evidence of igneous activity before the Middle Devonian, and neither the Meadfoot Beds nor the Staddon Grits have yet been studied from the point of view of the heavy minerals. The south of the promontory consists of Middle Devonian slates and limestones with slight traces of tuff at the passage from slate to limestone. The south-east consists of Lower Devonian Meadfoot and Staddon Beds with a patch of limestone forming Hope's Nose. Here inversion has occurred, and two bands of tuff require notice. The Staddon Grits at Smuggler's Cove are faulted against dolerite which forms a large mass 300 feet high and extending as far as Anstey's Cove. The intrusion is a laccolith, with the greatest thickness to the south and thinning out to the north. The intrusion is confined to the Upper Devonian slates. Above these, the Ilsham limestone is inverted with more or less shaly Goniatite limestone at the junction, and near the transition tuffs are usually found. On the north of Anstey's Cove the limestones are in great force, forming the high cliffs of Wall's Hill and Babbacombe; at the latter place slates underlie the limestones, and the Devonian is faulted against Permian rocks to the north. No traces of igneous rock are to be seen between Anstey's Cove and the south of Babbacombe Beach; here, a small intrusion forms the Red Rocks at Babbacombe Pier. In the slates under the limestone in the main cliff is a salic sill, and a more basic sill in the limestones. All these rocks above detailed are faulted against the Staddon Grits of Warberry and Lincombe Hills. To the west of the former is a syncline of Middle Devonian with schalstein or tuff at Ellacombe; near St. Vincent's Orphanage a spilite occurs. An intrusive sill of dolerite occurs in slates in the Upton Valley near the Daison; and, at St. Marychurch, tuffs are found associated with slates and limestone. The most westerly outcrop of igneous rock is near the Cricket Field, where a vesicular dolerite occurs in a small faulted patch of limestone. The rock is so completely decomposed that no further description of it can be given.

The most characteristic feature of the geology of the district is the impersistence of the limestones. Some of the detached masses are in association with slates, and may be in their normal position, but many do not pass down to slates, and were brought into position by thrusts or inversions.

III. The Explosive Phase.

A. Tuffs in the Middle Devonian.

At Daddy Hole is a high cliff of limestone over slate repeated on the Meadfoot side, and in turn faulted against Meadfoot Beds,

forming the base of Lincombe Hill. This imbricate structure is due to a thrust, probably in the Eifelian slates between the limestones. Where the limestones pass down to slates at the eastern outcrop, some traces of tuff were noticed, but in small amount.

At Hope's Nose the seaward end of the promontory is of limestone, with thin bedded limestone showing strong cleavage thrust over massive limestone, the whole being faulted to the west against thin limestones over Eifelian slates. There are two bands of tuff involved in a double fold of the thin limestones, and a well-marked thrust plane cutting these above. The upper band of tuff is 8 inches thick and the lower 5 inches. The former is coarse-grained, and the latter much finer grained. Both these bands disappear by fault to the south, and to the north they are repeated by a small fault and then continue out to sea.

Petrographical Note (Pl. IX, Fig. 1).—These sections show dark *lapilli* in a re-crystallized calcite matrix. The *lapilli* consist of iron oxides and a yellow decomposed glass-like substance with some chlorite. The majority are convex fragments, but some have concave outlines. In the Daddy Hole example, a few broken prisms were noticed with the shapes of felspars and a skin of dark glass, the crystals originally being felspars, but now formed of calcite. The *lapilli* have inclusions of calcite, or of quartz, but most of the latter is of the chalcedonic variety. The yellowish to dark decomposed glass and the shapes of the *lapilli* recall a palagonite tuff and indicate the basic nature of the earlier explosions. At Ellacombe, immediately north of the Church, schalstein and tuff are associated with limestone and slates.

These appear to be exceptionally impure limestones which have been sheared; no fresh specimens of the tuffs could be obtained. Exposures are now rare, the area being completely built over.

At Trumlands Quarry, St. Marychurch, calcareous reddish tuffs overlie limestone and are associated with slate, which in turn is under limestone, and beyond this to the north slate and tuffs again occur. The tuffs are hard and soft, the former again appearing to be impure sheared limestones.

B. Tuffs in the Upper Devonian.

These are restricted to Anstey's Cove, none having been found at Petit Tor.

Slates are above the dolerite, and the top of the cliff is of limestone, apparently nearly horizontally bedded. The passage from slates to limestone is gradual, the former becoming more calcareous and forming red, slaty Goniatite limestone (2). The tuffs are in close association with the latter.

In hand specimen these tuffs are dark red or purple flecked with patches of grey or bluish calcite. In thin section the ground is calcite, mostly clear and re-crystallized. The *lapilli* are of dark

glass, less decomposed than that in the Middle Devonian tuffs; small gas vesicles are often visible.

The volcanic eruptions occur at two horizons, associated with the change from slate to limestone in the Middle Devonian and the reverse in the Upper Devonian. The eruptions were of a basic nature.

IV. The Intrusive Phase.

A. The Black Head Laccolith.

This intrusion lies in the Upper Devonian Slates. The age of these has been proved by the occurrence of *Entomis serratostriata* (2), *Posidonomya venusta* (3), and of a trilobite referred by me to *Trimerocephalus* (4). At Anstey's Cove a clear section is well exposed, showing massive limestone over these slates, which are converted to spilosites at the junction with the dolerite. From this locality to Smuggler's Cove the coast cliffs are all of dolerite, with the exception of the limestone at the northern horn of Black Head. The petrography of the main intrusion will first be considered, followed by the petrography and detailed structure of the flanks, of which the section at Anstey's Cove will be detailed first, in order to indicate the evidence for the correlation of the Red Rocks at Babbacombe with the main mass and also of the small intrusion at Ilsham Manor.

Petrography of the Main Intrusion.—This is a partly ophitic, rather fine-grained dolerite. In the field it weathers to a dark greyish-brown surface, dark green when chipped ; the albitic segregations or veins to be described cannot be differentiated in the field. The most noticeable differences in the field are some wide veins or areas of red dolerite : microscopic evidence shows that this staining is due to the alteration of ophitic augite to limonite ; all stages can be traced from fresh augite to a pale brown nearly isotropic substance with black specks of magnetite, to a nearly opaque red limonite. The felspars show no alteration beyond the albitization and chloritization which is characteristic of the whole intrusion.

The ferro-magnesian mineral is nearly always an augite, usually ophitic ; smaller rounded or euhedral individuals occur, but these are more characteristic of the albitic segregations and of the flanks. It is nearly colourless with a maximum extinction angle of 45°. Decomposition in the green dolerite is to a plate of chlorite, in the red dolerite to limonite. In some sections small amounts of olivine are traceable, occurring either as small rounded isolated crystals or as a rounded inclusion near the edges of an augite plate. Its occurrence is quite comparable to the olivine in the albite-dolerite east of Trusham Station, Teign Valley (5).

The felspar is andesine with a tendency to oligoclase, and this is considered to be the original felspar, the larger individuals may be of this variety. But by far the larger amount of plagioclase

felspar is albite, proved by tests on the refractive index, and from optical characteristics. The amount of albite varies: in the albitic segregations all the felspar tested showed a refractive index below that of the hard balsam in which the sections were mounted; in the main mass some sections are practically all albite, in others about a quarter may be andesine. Orthoclase occurs associated with the albite. The latter may be in three varieties. Small rounded clear albites, in association with chlorite, are evidently secondary. The greater part is spongy albite filled with inclusions of chlorite. Clear laths of well-twinned primary albite also occur and become more important in the albitic varieties.

FIG. 1.—Dolerite glass penetrating silicified limestone, North Horn, Black Head.

FIG. 2.—Quartz and chlorite in albite dolerite, Black Head.

Quartz is usually present (Fig. 2); in some cases it may be secondary when associated with chlorite, but much of it is undoubtedly original, confirmation of this being found in the occurrence of patches of micropegmatite, and in patches of quartz between the felspar laths. The iron ore seems always to be ilmenite, much of it fresh, but some shows leucoxenic alteration. The association of titanium-bearing iron ore with albite has been described frequently. Apatite is common, usually in long thin prisms. Secondary changes other than albitization are confined to the formation of chlorite or limonite after augite, scattered epidote and a little pectolite. In the chlorite plates are some rounded chlorite or calcite rather different from the surrounding plate, and probably after olivine, but no characteristic magnetite-serpentine pseudomorphs were observed (6).

A Delesse-Rosiwal analysis was made, including quartz-dolerite, dolerite with olivine, and the more ordinary varieties. Areas of partially altered augite were calculated as augite, and a correction for the amount of chlorite in felspars was estimated at 3% of the

measured felspar areas. This rock is compared with the albite-dolerite of Trusham Station, Teign Valley (7), the latter analysis being a partial quotation. The Black Head rock is intermediate in character between the ordinary Trusham dolerite and its albitic segregation product.

ANALYSES OF DOLERITES.

	I.	II.	III.
SiO_2	46·73	54·77	58·47
Al_2O_3	18·73	12·65	16·11
FeO	10·14	11·08	6·90
MgO	3·56	6·85	1·58
CaO	8·62	4·42	0·94
Na_2O	3·54	5·08	4·34
K_2O	0·88	1·62	5·18
TiO_2	2·74	1·42	1·18
P_2O_5	0·37	0·76	0·27
H_2O	3·31	1·36	2·08
Etc.	1·35	—	3·24
	99·97	100·01	100·29

I. Albite-Dolerite, Trusham Station. Radley.
II. Albite-Dolerite, Black Head, Torquay. Rosiwal Analysis.
III. Albite-Dolerite (felspathic variety), Trusham Station. Radley 1. Sp. Gr. = 2·80.

The rise in the total alkalis and the increase in orthoclase indicated by the proportion of K_2O are noticeable ; and the TiO_2 is antipathetic to the SiO_2. The CaO shows notable decrease with rise in the proportion of SiO_2 ; the proportions of FeO and MgO may be anomalous owing to uncertainty of the composition of the augite, which was calculated as normative diopside ; the chloride being taken as clinochlore.

The most interesting feature of the Trusham dolerite is the occurrence of albitic segregation veins. Similar veins are now to be described from Black Head, but their exact relations are by no means clear, partly from lack of exposures and partly from the impossibility of differentiating them completely in the field, all the outcrops being weathered. This last suggests that they are segregations and not true veins.

Petrography of the Albitic Veins.—All these sections are characterized by abundant fresh albite, showing albite lamellæ (Pl. IX, Fig. 2). The most characteristic mineral is soda-orthoclase in rather large rhombs and plates, generally surrounded by a perthitic growth of chlorite and albite. Some large albite plates occur with chlorite forming a coarse perthite, recalling the augite-nepheline plates of a theralite. The larger part of the albite is in unaltered crystals with albite lamellæ. Between the larger individuals small rhombs of albite, often showing chequer structure, occur. A small amount of quartz is the final product of crystallization.

Augite occurs as small rounded crystals; one or two of these may be olivine, but the characteristic cleavages are not well developed in these small crystals. Apatite is abundant in long prisms, some

with a central inclusion of chlorite (8). The iron ore is ilmenite. Secondary alteration consists of spongy albite, with chlorite, some epidote, and very little tremolite. The texture is gabbroid.

Another section is finer grained, and the augite is here ophitic with some small rounded olivines; one larger olivine was noticed ophitic to felspar. The albite is nearly all fresh and twinned; with smaller albites, some chequered, in the interspaces. Orthoclase forms about one quarter of the felspars, and small areas of micropegmatite are the final products.

In the most salic of all the occurrences, calcite is abundant, and may be after augite, though few ophitic plates are visible, but much of the calcite is due to secondary veining. The bulk of the section is fresh albite, not chloritized, in small laths, showing albite lamellæ. In hand specimen the rock is yellowish-grey and syenitic in aspect. Apatite is in no great amount. Purplish patches occur and are composed of albite and hæmatite or ilmenite largely altered to limonite.

Petrography of the Flanks of the Intrusion.

1. *Anstey's Cove.*

Sections of green dolerite show fresh albite, much finer grained with some small phenocrysts of soda-orthoclase. The ground is of chlorite, but much of the latter is ophitic after augite. In the chlorite ground are some small granular albites, clearly secondary. The texture of the main part of the sections is ophitic and undisturbed; but some small crush lines are visible in places about one-eighth of an inch apart. Here the ilmenite is in small elongated dusty patches with chlorite wisps and some sphene. Between these the albites are broken and separated, forming augen.

The green dolerite from below the house in the Cove contains no fresh felspar; small secondary albites alone representing the latter. A few original quartz grains which contained apatites occur. Zoisite, apatite, quartz, and calcite are the remaining minerals. The whole section has been silicified and chloritized. Quartz, either granulitic or spherulitic, is abundant, filling the spaces between the irregular chlorites. The chlorite may be after mica, since micasization appears to accompany the quartz at Smuggler's Cove.

The contact alteration both above and below shows the intrusive nature of the dolerite, and the greater alteration above is characteristic. The spilosites vary in thickness, being usually about 6 inches with a characteristic platy parting parallel to the surface of the dolerite; this parting may sometimes extend into the dolerite. Cleavage affects these slightly. The unaltered dolerite is rather finer grained and shows the usual albitic character. The important feature is the silicification near the edges of the laccolith. This extends to the slates and in places obscures the contact: in one section a breccia fragment of dolerite was observed in slate partly surrounded by chalcedonic and spherulitic quartz which extended

in veining through the slate. This shows that movement took place after the consolidation of the dolerite and that the silicification was posterior to the movement. The sill forms the outer reefs as far as Anstey's Cove and there disappears from view. The petrographic characters show that it belongs to the albite-dolerite, since unaltered material occurs in part.

2. *The Faulted Boundary at Smuggler's Cove.*

A small patch of dolerite outcrops near the entrance to Ilsham Manor and traces of it are to be seen in the new Ilsham Drive to the south. In thin section small ophitic augite occurs in quantity. In addition are small rounded augites and a few grains of more or less altered olivine. The ground is of chlorite and calcite. The felspars are either oligoclase-andesine or albite with some small rhombs of orthoclase. Clear spaces occur and in ordinary light appear to be quartz, but polarized light indicates that they are quartz-albite fine-grained pegmatite, and a difference in refractive index can be traced by the Becke method. Apatite is abundant and the iron ore is mostly hæmatite, though ilmenite also occurs. This patch is correlated with the main mass on the evidence of the micropegmatite and small olivines, together with the albite and hæmatite, but is rather more basic.

At Smuggler's Cove occurs the albitic vein already described. In the adjacent cliff is a well-defined crush line and in association with this are numerous quartz-epidote veins. The dolerite near these veins contains darker patches and in the field these were considered to be xenoliths; a thin section (Pl. IX, Fig. 3), however, shows that they are essentially altered dolerite in which some albite and augite remains, but the ilmenite has vanished and aggregates of strongly polarizing sphene replace it. The rest of the section consists of quartz, epidote and apatite. The silicification has followed the crush lines.

The dolerite is much reddened near the fault and the junction with the fault breccia cannot be determined in the field. Sections consist of a brecciated dolerite in which the latter is gneissose with development of quartz and white mica. Spherulitic and chalcedonic quartz also occur and probably metasomatism similar to that at Anstey's Cove had taken place here, but its effects are masked by the subsequent brecciation. Siderite rhombs occupy the rest of the section and crystallized specimens are to be found in the cavities of the fault breccia. The latter is a couple of feet in width. Numerous quartz veins occur near the junction as well as along the crush lines. Calcite veining is prominent locally.

3. *The Red Rocks, Babbacombe.*

The dark green rock below tide level attracts attention from its being rather like a picrite. The upper red rock is very fine grained but no junction can be traced. The dark green rock contains a

large amount of augite, some subophitic but mostly euhedral, with some small grains of olivine. The latter is present in small quantity only and the appearance in hand specimen is deceptive. The original felspar is oligoclase with a tendency to andesine but most is chloritized albite; a certain amount of fresh twinned albite also occurs. Chlorite and calcite are decomposition products. Immediately above this the rock is much calcitized with chlorite and a few olivine pseudomorphs. Apatite in all the sections is large and rather abundant. The iron ore is ilmenite. Immediately below the red rock the dolerite becomes finer grained but is much calcitized, the felspars being oligoclase-andesine and albite. Rounded calcite grains in augite plates are considered to be olivine pseudomorphs.

The red rock is entirely unlike the rest, consisting of some very small felspar laths in a nearly opaque ground of iron oxides and limonite. It forms the selvage to the intrusion and is entirely comparable to similar selvages described from Anglesey by E. Greenly (9). An isolated section would most probably be diagnosed as a basalt selvage, with lateritic alteration.

These rocks are correlated with the Black Head dolerite on the evidence of olivine, albitization, fresh albite and some quartz-hæmatite veins cutting it, but like the Ilsham Manor rock, it is more basic. It is possible that mineral stratification has occurred in the production of the darker rock at the base, but this is uncertain since the large development of calcite in the lighter rock may explain the differences noted in the field.

4. *The Section of the Northern Horn, Black Head* (10).

The limestone forms an anticline which disappears under the sea both to the north-west and south-east. Below this cleaved tuffs occur. The whole is intersected by a highly inclined thrust. On the north-west side of this is a small patch of schalstein. The low cliff above the limestone platform is formed of yellowish and greenish weathered slaty material. These are in greater force on the south-east and lie above the limestone down to the sea-level. The massive limestone has yielded Alveolites, etc., and the slaty limestone immediately in contact with it has yielded Goniatites. Here, the succession is normal, whereas to the north at Anstey's Cove the succession is the inverse of this.

Petrographical Note (Fig. 1).—The ground is a limestone with numerous quartz crystals and shows the typical character of a silicified limestone. The darker mass on the edge of the field is formed of partially decomposed doleritic glass and fine-grained dolerite presenting a distinct, but thin, chilled edge to the limestone. Quartz veins cross all the sections here described and show few strain shadows, whereas most of the quartz of the silicified limestone presents strain shadows. The quartz in the veins has crystallized perpendicular to the walls. In sections from nearer the dolerite in the upper part of the cliff a few small felspars were

found; these are of basic andesine, due to absorption of the limestone. This section shows microscopic thrusts and the calcite of the limestone has been injected by very thin veins of glass with a line of chlorite in the centre, surrounding most of the calcite grains. There is a slight development of white mica, due most probably to thrusting.

In the field no boundary can be traced between the dolerite-limestone mélange and the dolerite. Quartz veins cut the whole. The boundaries well marked in the field, such as that above the massive limestone, are due to erosion along local thrust planes. It is probable that the base of the intrusion is either here, or not far below sea-level. This suggestion is supported by the occurrence of quartz veins and silicification of the limestone, since few quartz veins or evidence of silicification have been found except near the margins of the intrusion.

Metasomatism connected with the Dolerite.

In the above, mention has been made of quartz-hæmatite veins and silicification of the dolerite. The chief development of these phenomena is at Anstey's Cove. In the low cliffs, immediately above where the sill leaves the main mass, quartz-jasper veins are in force, attaining a thickness of six inches. Examination of crushed material revealed the presence of hæmatite. The latter occurs as the micaceous variety in the slates to the north where definite mineral veins of quartz-hæmatite cut across the slate cleavage.

The dolerite in the most advanced stage of silicification is in the condition of a schist; the above-mentioned crush lines coalesce; apatite is abundant and is always broken; the ilmenite is broken, dragged out and converted to leucoxene. Chlorite laths with a flow structure represent the doleritic material. Calcite and quartz form the infilling. The latter is later than the calcitization, since it has cut across the calcite veining. This quartz may be granular, but is oftener chalcedonic showing numerous small spherules, giving a fair cross under a high power.

Hæmatite does not appear to be a usual associate of mineralization due to a basic intrusion. The date of the metasomatism is fixed by the fact that the veins cut across the cleavages of the slates; and therefore is the last phase of igneous activity. The dolerite was earlier than the cleavage because the spilosites are partially affected by it; and earlier than the crush lines, along which silicification appears to have proceeded most easily.

No other evidence of such metasomatic changes, except from the flanks of this intrusion, has been obtained from the area under consideration and its localization here appears to support the theory put forward by E. Greenly (11) that thrusting, cleavage and intrusions are the necessary factors in its development. That the movements were dominantly of the nature of thrusts is shown by the section at Babbacombe Cliff, to be considered immediately.

B. The Babbacombe Intrusions.

The structure of Babbacombe Cliff is essentially a limestone series overlying slates. Both have been affected by numerous drag-folds, with their axes dipping eastwards, and cut by minor thrusts. The exact relations of the limestones and slates have not yet been worked out: locally limestone is interbedded with slate. These rocks are cut off by fault to the north against Permian breccia-conglomerate and sand-rock. To the south is a steep valley in slates, the limestone retreating locally from the cliff; further south the whole cliff of Wall's Hill is limestone. Two distinct intrusions occur in the main cliff. The upper is involved in the folding and thrusting of the limestone, and its relations are intricate. This igneous rock swells locally into small domes, and is here fairly fresh, but it can be followed into a dark red rock which can be traced apparently as a sill along the face of the cliff and upwards, cut by the surface of the plateau. The sill is faulted slightly on the south; to the west a small outcrop of similar rock occurs in the Babbacombe Road. There is no contact alteration of the limestone.

Petrographical Note (Pl. IX, Fig. 4).—In hand specimen, the rock presents no apparent differences from a fine-grained dolerite, but in thin slice the felspars are arranged in characteristic sheaf-like groupings as in many lamprophryes and essexitic dolerites. This lath-shaped felspar is mainly oligoclase-albite with refractive index below that of balsam and nearly straight extinctions. The remainder of the felspar is either in short tabular euhedral crystals or as an infilling of part of the ground: this is non-striated, often shows two cleavages and carlsbad twins, and its refractive index is well below that of balsam, and is referred to orthoclase. Chemical analysis alone would determine the true relations: microscopic examination would appear to show that the rock is monzonitic.

The ferro-magnesian mineral is always an augite nearly colourless to greenish-brown, and with an extinction angle of 45°. This occurs in two generations: as a few phenocrysts and as small grains scattered in the ground. Many plates of chlorite or calcite occur after the larger augites: calcite is common throughout the rock. Apatite is found in quantity. The iron ore is always ilmenite, and is fairly abundant. Most of it is altered to leucoxene, and occasionally to sphene. Epidote, zoisite, and calcite are decomposition products, in addition to the chlorite: and some of the orthoclase is much clouded by micaceous material in addition to calcite. The texture of the felspars and the two generations of the ferro-magnesian mineral, together with absence of contact alteration, are all characteristic of the lamprophyres. The rock may be described as an augite-lamprophyre.

The decomposed portion already referred to shows similar felspars but no fresh augite, the latter being calcite with a dark border of ferric oxide. Further alteration is represented by complete granula-

tion of the felspars and the development of minute micas, but the augite phenocrysts can still be traced by their calcite pseudomorphs.

The lower outcrop of igneous rock is more continuous and can be traced in the dark slates along the base of the cliff. Numerous fragments of slate are included, and thin veins penetrate the slates. The cleavage of the latter affects these smaller veins, and the jointing of the igneous rock—a porphyrite—dips in the same direction. This jointing is of a columnar nature nearly perpendicular to the surface of the sill, but affected slightly by the cleavage movements.

Petrographical Note (Pl. IX, Fig. 5).—All sections show that the rock is homogeneous, except for scattered vesicles filled with chlorite or calcite near the margins, and for the greater development of glass near the contact and in the thin veins. A section from contact shows a dark glass enclosing both phenocrysts and slate fragments, but the latter are not sensibly spotted. Slides from the centre of the rock show two generations of felspars in a green or brown glassy ground. A little chlorite also occurs in this ground and the glass shows incipient alteration to vermicular chlorite. No other ferromagnesian mineral has been observed. Ilmenite dust is in small amount. Calcite is a common decomposition product, and apatite is very scarce.

Rosiwal analyses of both these rocks are here given. The Black Head rock is included for purposes of comparison :—

ANALYSES.

	I.	II.	III.
SiO_2	47·99	54·77	58·05
Al_2O_3	9·58	12·65	12·72
FeO	3·80	11·08	3·85
MgO	14·15	1·85	7·13
CaO	7·56	0·94	4·84
Na_2O	2·56	4·34	6·90
K_2O	3·52	1·62	1·90
TiO_2	2·37	1·42	0·96
P_2O_5	0·78	0·76	nt. det.
CO_2	3·52	nt. det.	1·87
H_2O	3·95	1·36	1·64
	99·78	100·01	100·06

I. Augite-Lamprophyre : Babbacombe Cliff, Torquay.
II. Albite-Dolerite : Black Head, Torquay.
III. Soda-Porphyrite : Babbacombe Cliff, Torquay.

The felspar phenocrysts are either orthoclase or albite ; the former being most probably a soda orthoclase, as most sections have the characteristic streaky appearance of that variety. The lath felspars of the second generation are all albite, proved by a Becke determination in thin slice, and on crushed material by the Van der Kolk method. This rock was described by Busz (12) as a labrador-porphyry rock, allied to the leucophyres. But no traces of labradorite were found. The albite is largely in excess of orthoclase, and places the rock in the porphyrite group ; its lack of

ferro-magnesian minerals shows affinities to the bostonites, but its texture refers it to the former group. It may be described as a soda-porphyrite.

This rock and the augite-lamprophyre, above described, may be regarded as complementary rocks in the same sense as the bostonites and camptonites are complementary.

The augite-lamprophyre was then calculated to percentages of oxides; and, in order to institute a comparison between the three associated rocks, the glass in the soda-porphyrite was calculated as augite. This was selected as being probably the most basic mineral which would have separated under different conditions of cooling: hence the computed analysis is the most basic possible. Yet, the comparison indicates that the Babbacombe sills may be regarded as more basic and more acidic differentiation products from the doleritic magma; the intermediate or average composition of which is represented by the analysis of the Black Head albite-dolerite, here repeated. In analyses I and III the augite and glass were calculated as normative diopside; and the chlorite as theoretical serpentine, there being no indication of the origin of the chlorite in the soda-porphyrite.

Here again the antipathy of the TiO_2 to SiO_2 and Na_2O is to be observed. The proportions of MgO and CaO are affected by the unknown composition of the glass and chlorite and by the large percentages of calcite.

The large proportion of alkalis and the rapid rise of the Na_2O are notable features.

The quoted analysis of the albitic segregation veins of the Trusham dolerite (13) on page 198 above, may be compared most instructively with that of the soda-porphyrite. The silica and total alkali percentages are nearly equal, and the titanium is low in both. Further, the total alkalis in the albitic veins at Knowle's Hill, Newton Abbot (14), are of the same order. These figures may here be repeated :—

	% SiO_2.	% Total Alkalis.	% TiO_2.
Trusham Segregations .	58·47	9·52	1·18
Newton Abbot Veins . .	53·59	9·82	trace
Soda-porphyrite . .	58·05	8·80	0·96

There appears to be evidence for the suggestion that here the final albitic phase took the form of a definite later intrusion, instead of a large development of albitic segregations or albitic intrusive veins. In the Teign Valley segregation was dominant, at Newton veining, at Torquay a definite intrusion. Unfortunately, field evidence, proving that the soda-porphyrite was later, cannot be submitted.

C. The Smaller Intrusions.

In the Upton Valley, near the Daison, there is an outcrop of dolerite, now concealed by buildings. Former notes show that the

slates were hardened, proving its intrusive nature. The rock is very much decayed, and but slight reliance can be placed on the evidence as to correlation.

In thin section, a few clearer laths and phenocrysts are altered felspar, replaced by chlorite, calcite, or chalcedonic and spherulitic silica. The ground is of dark glass and chlorite; the latter shows rather high double refraction, and is fibrous with the fibres perpendicular to the edges of the glass it replaces. This rock approaches most nearly to the Babbacombe soda-porphyrite on account of felspar phenocrysts in a strongly glassy ground.

The small intrusion near the Cricket Field and its decayed condition were noticed during the discussion of the field evidence.

The igneous rock outcropping in St. Vincent's Road is considered here for convenience, though in all probability it was a lava. It occurs above red slates, and mapping clearly indicates the unconformity of the limestone to it. These slates are usually considered to be Eifelian, but the character of this rock suggests an Upper Devonian age for them.

Pl. IX, Fig. 6.—In thin slice it is recognized as a typical spilite, though rather coarse grained. Numerous felspar laths with slight flow structure are scattered in a dark brown partially decomposed glass. Where this felspar is sufficiently fresh for a determination, it is oligoclase-albite. The vesicles are small and filled uniformly with calcite, showing strain lamellæ. Chlorite and a black dust are found in the ground, and as decomposition products of the glass.

V. Correlation of the Igneous Rocks.

The Black Head albite-dolerite has been shown to extend from Smuggler's Cove to Anstey's Cove and to include the isolated patches near Ilsham Manor. Further, an extension of this mass outcrops at Babbacombe Pier and is also in association with red slates. Now, Ussher suggested that these slates were probably Upper Devonian, and the petrographic evidence goes far to support this conclusion.

The Babbacombe Cliff intrusions are found to be complementary rocks, and the various detached outcrops of the upper sill have been proved to be parts of one augite-lamprophyre, even including the red decomposed rock infolded in the limestone. The horizons of these intrusions have been shown to be rather definite and hence they were injected anterior to the tectonic movements. The Daison intrusion is somewhat doubtfully suggested as belonging to the Babbacombe soda-porphyrite, either identical or complementary.

The St. Vincent's Road lava has been shown to be a typical spilite. Now, in South-East Devon the spilites appear to be restricted to the Upper Devonian horizons and its occurrence in these red slates is strongly suggestive of their Upper Devonian age. This would indicate the inversion of the limestone to the west, which conclusion is further supported by the mapping.

It is not possible to correlate the tuffs. The evidence furnished

by them may be summarized as :—The explosive phase occurs at two horizons, namely, the Middle and Upper Devonian, in each case accompanying a lithological change. This change is gradual and shows that the tuffs were marine deposits.

VI. Relations to the Tectonics.

Emphasis has already been laid on the evidence that the main intrusions remain each in one particular horizon. This proves that the injections took place before the main folding movements. It is likely that some tilting had previously occurred since a sill approaches the limits of its own stratigraphic horizon in places ; for example, the soda-porphyrite sill at Half Tide Rocks has roughly 100 feet of slate above it, but at its northern outcrop less than 20 feet of slate. This conclusion is supported by evidence from other igneous areas, but cannot be proved in this case, since the outcrops seem largely to be along the strike of the formations.

The main folding was posterior to the intrusive stage : conclusive evidence of this is offered by the sill in the upper part of Babbacombe Cliff. The extensive minor thrusting was also posterior to intrusion. The section at Hope's Nose may conveniently be discussed. The tuffs are involved in the folding with the axes of the isoclines dipping S.S.E. These folds are cut by a thrust plane dipping slightly to the E.S.E. In the cliff facing south is a clear section showing an overturned fold passing to a minor thrust, and its axes dip E.S.E. Below this is a major thrust cutting across the plane of the minor. Both folds and thrusts are affected alike by the cleavage, its dip being S.S.E. throughout. The cleavage throughout the promontory varies only from S. to S.S.E., and is clearly due to a directive force from one definite direction. From these facts it is clear that there have been two periods of folding, and that the thrusting was the last stage of compressional movement. The earlier folding is Armorican, and the later is Pennine in direction ; and, perhaps, in age as well. The involved structure of the area is due to the syntaxis of these movements.

Thrusting both in the field, and of microscopic nature, is to be found at the base of the Black Head mass ; the incompetent slates above it do not yield definite evidence of thrusting on the large scale, but it is probably here that the planes bringing the Ilsham limestone into its inverted position are to be found. The relatively competent dolerite would act somewhat as a horst. The porphyrite sill may be cited as an example of less movement owing to its being intruded into slates, whereas the lamprophyre sill in limestone has been almost equally affected by the folding.

The relations of the igneous masses to the faulting rest on unsatisfactory evidence. The axes of the drag folds as far as worked out seem to swing round to the east instead of from the south-south-east when observations are made to the northward. This suggests that the Warberry Hill Staddon Grits acted as a horst, in which

case the strike faults were anterior to the folding and therefore to the intrusions. But further evidence is essential. The E.–W. faults are all later than the folding and are post-Permian ; these faults are characteristic of the latter formation. Movement along the strike took place again after the folding and thrusting as can be ascertained from the faulted inversion at Hope's Nose, and from a study of the shatter faults at Redgate Beach.

The occurrence of vulcanism at the lithological changes in the strata, the recognition of a spilite and the dominant natrian character of the magma are in accordance with the Harker-Bowen principle (15) that natrian types are associated with subsiding areas. The distribution of the Permian deposits round Torbay indicates that the ancient shore line roughly coincided with the present, and this subsiding movement was repeated in Permian times. It is possible that the area of Torbay was the site of a cauldron inbreak. Such movement, prolonged to the Permian, would explain several patches of the latter faulted against the Devonian to the west, as at Saltern Cove.

The Age of the Intrusions.

No exposures are visible where these intrusions may cut one another. It has been suggested from the petrographic evidence that the soda-porphyrite may be the last phase of differentiation. The large proportion of albite molecules shows clearly that they are co-magmatic and probably are not far from being contemporaneous. The most important conclusion to be drawn as to their age is that they are of post-Culm date. It has been shown that the albite-dolerite is exactly comparable to the Teign Valley rocks which intrude and alter the Culm of that locality. Further, the sill at Knowle's Hill, Newton Abbot, forms a connecting link between them and the Torquay rocks. They are all characterized by high soda content and by an albitic phase as the last product of crystallization. The evidence seems irresistible that they are products of one igneous age and of one magma reservoir ; the earliest products of which, that can be identified, are the Upper Devonian spilitic lavas. The tuffs are too decomposed to prove that they were also spilitic ; glassy, they certainly were.

If, then, the evidence be accepted that the Black Head albite-dolerite is post-Culm, it follows that all the tectonic movements affecting these rocks are post-Culm in date. That these movements were pre-Permian is proved by the latter rocks being affected only by shatter faults. This conclusion brings the tectonics of this area in accordance with those of the Teign Valley and Dartmoor, which are post-Culm. Further, it limits the age of the Dartmoor folding to pre-Permian ; this is supported by the evidence of the breccias of the Crediton Valley.

VII. Summary and Conclusions.

The Middle and Upper Devonian rocks of the Torquay Promontory give evidence of a volcanic phase in Middle Devonian times, recurring

W. G. S. photomicro.

IGNEOUS ROCKS, TORQUAY.

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in the Upper Devonian, and completed by a hypabyssal phase, which was post-Culm and pre-Permian. The tuffs are basic in nature, of glass and lava fragments, cemented by calcite. The only lava recognized is a spilite, probably Upper Devonian.

Complementary rocks: a soda-porphyrite and an augite-lamprophyre, have been recognized at Babbacombe.

An albite-dolerite is described from Black Head, carrying small amounts of olivine and with the characteristic albite-segregation veins. This mass has been shown to include the Ilsham Manor and the Red Rocks outcrop at Babbacombe. Metasomatic change due to silicification is characteristic of its flanks: this is especially developed at Anstey's Cove, where quartz-hæmatite veins are later than the cleavage of the slates.

It has been shown that there is strong evidence for the post-Culm date of this intrusion and hence for the tectonic movements of the area. The latter have been in the sequence:—tilting, intrusion, folding, thrusting, cleavage, and faulting, Some strike faults may be anterior to all these, but were repeated after the cleavage movements.

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EXPLANATION OF PLATE IX.

FIG. 1.—Volcanic tuff; Hope's Nose. Lapilli of iron oxides and decomposed glass. The west and south-west of the field consists mainly of calcite matrix. Quartz inclusions are visible in the north-west fragment. ×20 diam.

FIG. 2.—Pegmatitic albite segregation, Black Head, Ilsham. Rhombs of soda-orthoclase surrounded by perthitic chlorite and albite; the south-west and south rhombs are at extinction: An albite plate occupies the north-north-west position, and on the south-south-west edge is a small chequer albite. Ilmenite occurs in the centre cut by a long apatite prism;

another ilmenite lies immediately to the north-east. Small quartz grains are to the east of the central ilmenite. ×25 diam.

Fig. 3.—Quartz-sphene-epidote vein in Albite-Dolerite, Smuggler's Cove. The unaltered dolerite is to be seen on the east, with an albite prism on the north-east edge. The clear spaces are quartz with strain-shadow extinction. The rounded aggregates are sphene. Many small epidote prisms are scattered in the field, two are well shown south of the central sphene. The quartz grains contain a few apatite prisms, as in the crystal on the east. ×20 diam.

Fig. 4.—Augite-lamprophyre, Babbacombe. Laths of oligoclase-albite in sheaf groupings. A small euhedral orthoclase lies radially in the south-west. The ground consists of chlorite, apatite, ilmenite, and calcite. A calcite-chlorite pseudomorph after augite is visible on the south-east border. Augite phenocrysts occur in other parts of the slide. ×20 diam.

Fig. 5.—Soda-porphyrite, Babbacombe. A large albite phenocryst is seen on the west and soda-orthoclase on the east and north-east. Smaller albites occur in the ground of chlorite, glass, and a few ilmenites, A secondary calcite vein is seen in the south-east quadrant. ×20 diam.

Fig. 6.—Spilite, St. Vincent's Road. Laths of oligoclase-albite with flow structure east–west. Vesicles of calcite with strain lamellæ. The matrix consists of chlorite and dark-brown glass. ×20 diam.

The Geology of Roade Cutting.

By Beeby Thompson, F.C.S., F.G.S.

(WITH PLATES X AND XI.)

ROADE cutting was considered to be one of the great works in the construction of the original London and Birmingham Railway (afterwards the London and North-Western Railway) between 1833 and 1838, being about 1½ mile in length, of considerable average depth, a good part of which consisted of hard rock—the Great Oolite Limestone.

The original line did not pass through Northampton, the nearest main line station to Northampton then being at Blisworth. In 1875 a Bill was passed enabling the railway company to make a new loop line to go through Northampton, starting on the south at Roade station (about 60 miles from London) and ending at Rugby. Roade cutting was again an important part of the work, and a particularly interesting section of rocks was exposed near to bridge 2[1] in 1880, an account of which was given in the *Journal of the Northamptonshire Natural History Society* for that year (vol. i, pp. 88–9).

In the original cutting difficulty was occasioned by the inflow of water from the Great Oolite Limestone mainly towards the northern end on the western side, which was got over by conveying the water under the line in a conduit.

In the necessary widening and deepening of the line on the eastern side, when making the loop line, more water was encountered from other beds below the Great Oolite Limestone, which water was similarly dealt with.

The deepening of the cutting, however, exposed clay beds of the

[1] The bridges are here numbered 1 to 6 from north to south to facilitate references. See diagram, Plate X.

Upper Lias, with the consequence that some few years later (Nov., 1891) a great slip occurred. To remedy this slip and prevent its recurrence the load above the deep part of the cutting was lightened by cutting back the upper rocks, and great iron girders were stretched across the deepened cutting at top and bottom against similar props on the face of the brickwork lining the trenched part.

For a considerable distance northwards of Roade station the basement bed of the cutting is the Great Oolite Limestone, and it is nearly horizontal. As the newer loop line dipped below the level of the older line, however, older beds, the Upper and Lower Estuarines for example, were cut through and ultimately the Upper Lias. Not only did this naturally result from the character of the operations, but the exposure of lower and lower beds was aided in the northern half of the cutting, i.e. beyond bridge 3, by a distinct rise of the beds themselves northwards of about 10 feet in a quarter of a mile, as shown in the diagram, which inclination was even increased towards bridge 1, that is towards the valley on the north.

The Great Oolite Limestone was best exposed between bridges 2 and 3 when remedying the slip, where it was cut back in steps or ledges, which gave a better opportunity for examination in detail than could be obtained from a vertical rock-face. Besides this, on account of the southward dip of the limestone, higher beds were successively exposed in that direction. The observations made at this period are embodied in the following notes and have not before been published.

GEOLOGICAL SECTION OF ROADE CUTTING.

	ft. in.
Glacial Beds.	
1. Chalky Boulder Clay (much); Gravel or Sand (little); disturbed and included portions of rocks from Cornbrash to Great Oolite Limestone. (See remarks on Glacial Beds.)	0′ 0″ to 20 0
Cornbrash.	
2. Hard, semi-crystalline limestone weathering whiter than the Great Oolite Limestone. Although a good amount well exposed, very little certainly in situ. Fossils abundant, including :— *Bulla undulata, Pseudomonotis echinata, Isocardia minima, Myacites decurtatus, Pecten vagans* (many), *Pecten demissus* (many, large), *Trigonia* sp ?, *Ornithella obovata* (many), *Anabacia complanata, Serpulae*, etc. . . .	2 5
Intermediary Bed.	
3. At one place where Cornbrash seemed to be in situ it was underlaid by a layer of hard brown shale resting on an irregular ferruginous layer with some fossils not to be identified	0 7
Forest Marble.	
4. (*a*) Variegated Clay, red and green. Band of hard shale, quite stone in places, about 6 inches from top; clay less variegated below. Then a layer of fibrous carbonate of lime ("Beef") about 1 inch thick for some distance. Much selenite in small elongated crystals. Base a hard bed with :—*Ostrea sowerbyi, Perna obliqua* ?, *Sphaera madridi, Placunopsis socialis* . . . . . 2 ft 0 in.	

ft. in.

(*b*) Purplish Fossiliferous Clay, irregular, with abundant *Ostrea*.

(*c*) Greenish Clay, with frequent slight alterations of colour and fossiliferous layers; indeed, where it joins on to the Great Oolite Clay below crowded with shells, mostly lamellibranchs, but too friable to get; and much selenite in small crystals:—*Corbis elliptica* ?, *Cyprina* ? . 2 ft. 10 in. 4 10

GREAT OOLITE CLAY.

5. Purple and variegated clay as shown below:—

(*a*) Clay of almost uniform purple tint as seen from a distance, but actually variegated. Much carbonaceous matter and actual wood in parts. Thin crystals of selenite abundant on and in the wood. Layer of bright red concretionary ironstone nodules a little below the middle. 8 ft. 0 in.

(*b*) Variegated clay and very variable bed altogether; bands of various colours, with *Plants*. Sequence at one place:—

Red, yellow, and green clay with *Vertical Plants* 1 ft. 6 in.
Irregular band of ironstone . . 3 in. to 8 in. 10 0

INTERMEDIARY BED.

6. (*a*) Bluish and ferruginous clay with *horizontally bedded carbonaceous matter* . . . . 0 ft 6 in. to 1 ft. 0 in.

(*b*) Oyster-bed—an argillaceous and ferruginous bed abounding in oysters, mostly comminuted, and may be other shells; with selenite and *horizontally bedded carbonaceous matter* and *drift wood*, the latter chiefly at junction with bed next below . . . . . 0 ft. 6 in. 1 0

GREAT OOLITE LIMESTONE. 22 ft. 8 in.

7. PLANT BEDS. (*a*) Soft, light-grey, argillaceous limestone with rather thick, *branching upright plant stems*. Also many fossils, but rather crushed:—*Isocardia*, *Mytilus*, *Serpula* 1 ft. 0 in.

(*b*) Purer limestone, much harder (required blasting), though some plant stems ran straight up through both beds. Fossils in this the same as in (*a*), but not crushed 1 ft. 6 in. 2 6

8. (*a*) Very thin shaley parting. . } 0 ft. 10 in.
(*b*) Hard limestone very like (*b*) above }

(*c*) Ferruginous shaley limestone with *Ostrea* 0 ft. 2 in. 1 0

9. CORAL BED. (*a*) Hard limestone with *Coral* in patches, much converted into calc-spar, and very commonly and extensively bored by *Lithodomus inclusus*. Most of the common Great Oolite fossils present, but difficult to get:—*Natica*, *Isocardia minima* (many), *Pecten*, etc. The Coral here not good for identification purposes, but much better specimens obtained from the same horizon at Roade village. *Thamnastraea lyelli* ? is probably the predominant form 1 ft. 0 in. to 1 ft. 9 in.

(*b*) Marl passing almost imperceptibly into (*a*) 0 ft. 9 in. 2 0

10. INTERMEDIARY BED. (*a*) Limestone, hard, fine-grained, flaggy, largely oolitic. Very few fossils indeed, none identified . . . . . 4 ft. 3 in.

(*b*) Sandy-looking limestone or dirt-bed . 0 ft. 7 in. 4 10

11. TEREBRATULA BED. Limestone, largely oolitic, with a good variety of fossils:—*Cyprina islipensis*, *Homomya vezelayi*, *Isocardia minima*, *Pholadomya*, *Clypeus*, etc. This appears to be the particular horizon in this neighbourhood of certain large Terebratulæ which Mr. Buckman has named *Kutchithyris* aff. *circumdata*, Desl. . . . 1 0

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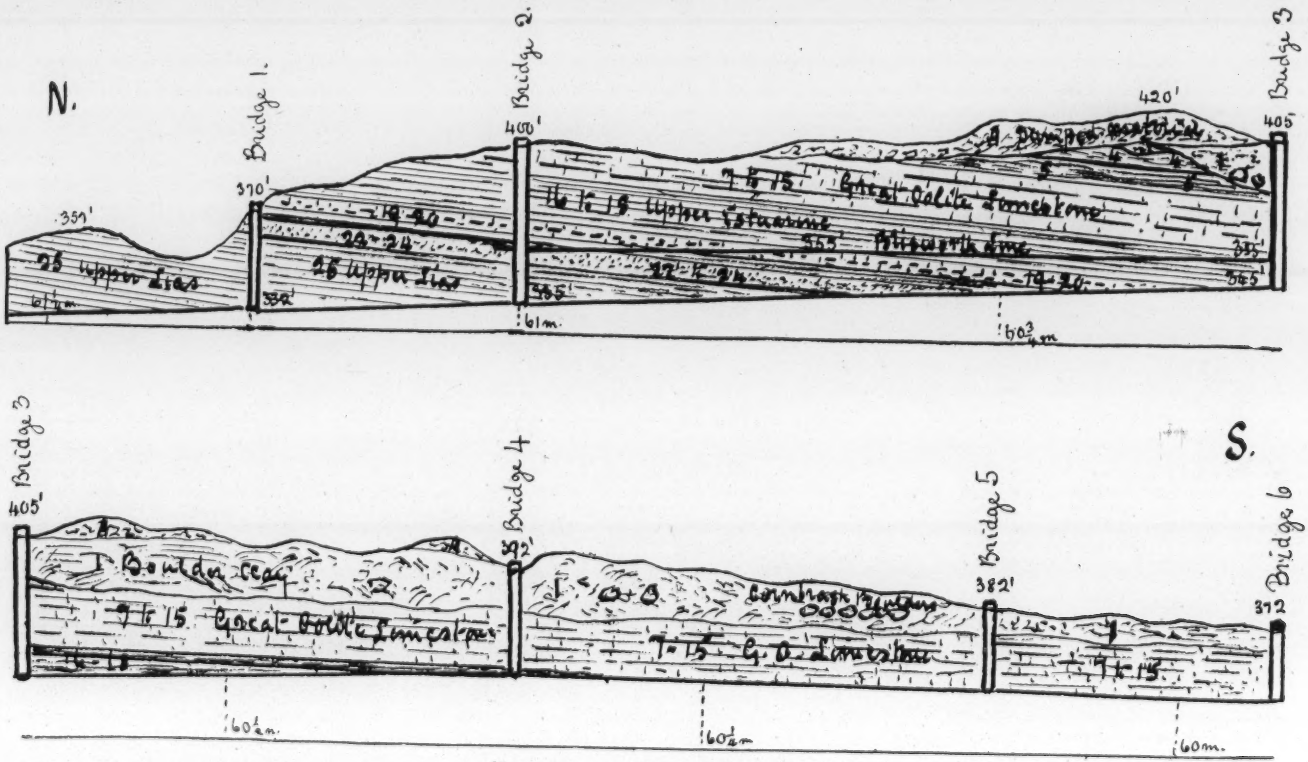


SECTION OF ROADE CUTTING.

Horizontal scale, 10 in. = 1 mile; vertical scale, $\frac{1}{5}$ in. = 10 feet.

UNCONFORMITY ?

		ft.	in.
12.	INTERMEDIARY BED. Limestone, false-bedded, made up of comminuted shells of various kinds, including *Ostrea* and many echinoderm spines and fragments. Irregular in character and thickness, and evidently a derived bed in the main	0	9
13.	NERINAEA BED. Oolitic limestone, highly fossiliferous, but gasteropods showing mainly in the very hard middle part, and most difficult to get out; other fossils obtained more easily from upper and lower parts:—*Hybodus, Nerinaea* (many), and other gasteropods, *Cyprina loweana, Cypricardia rostrata, Isocardia minima, Pecten lens, Pholadomya, Clypeus, Acrosalenia, Anabacia complanata* (many), Coral 1 ft. 10 in.		
	The Terebratulæ here are also large and what have usually been described as *T. maxillata* (*Epithyris bathonica* S. Buckman ?). Rhynchonellæ occur sparingly, but none like those occurring so abundantly in the Rhynchonella Beds below. One large specimen from here named *Rhynchonella* cf. *dromio* S. Buck.	1	10
14.	Darker, bluish limestone, more argillaceous than above .	0	6

NON-SEQUENCE. INFERENTIAL UNCONFORMITY.

15.	RHYNCHONELLA AND PHOLADOMYA BEDS. (*a*) Hard, blue-hearted limestone containing *Greslya peregrina* ?, *Isocardia minima* (many), *Pholadomya heraulti, P. deltoidea, Terebratulæ* (*Epithyris*), and *Rhynchonellæ* 1 ft. 9 in.		
	(*b*) Red sand and blue clay, variable . . . 0 ft. 9 in.		
	(*c*) Blue, argillaceous limestone in two or three beds with thin partings of marl. Exposed surfaces and joints give variety of colour—blue, red, white. Very fossiliferous with a somewhat different assemblage of forms to beds above:—*Nautilus baberi* ?, *Homomya vezelayi, Modiola imbricata, Modiola* sp. ? *Pholadomya* (many), *Terebratula* (*Epithyris*), *Rhynchonella* (most abundant), *Acrosalenia* 5 ft. 9 in.		
	The predominant feature of these beds is the occurrence in them of great numbers of a rather small *Rhynchonella* which until recent years has always been recorded as *Rhynchonella concinna*, but according to Mr. Buckman belongs to the *varians* group, and probably includes several at present unnamed species	8	3

UPPER ESTUARINE SERIES. 16 ft. 0 in.

16.	ABOVE LIMESTONE [NEAERAN BEDS]. (*a*) Blue shale or clay, rather hard, passing downwards into a bluish clay with *vertical plant-markings* enormously abundant. Uncertain junction with (*b*) . . . 1 ft. 6 in. to 3 ft. 0 in.		
	(*b*) Dark green clay (light green after exposure) with abundant *plant markings* . . . 2 ft. 10 in.		
	(*c*) Darker green clay with *Corbula attenuata* ? 2 ft. 0 in.		
	(*d*) Light green calcareous clay, hard and brittle when dry, very fossiliferous, but practically all casts not easy to identify. *Plants, Astarte, Corbula buckmani* ?, *Cyprina loweana* ?, *Modiola, Placunopsis socialis*, etc. 5 ft. 3 in.	12	0
17.	(*e*) PLACUNOPSIS BED. A dark grey clay, extraordinarily fossiliferous, more fossils than matrix. Although the fossils are well preserved they are so thickly placed and so extremely fragile that none can be got out intact, but the predominant forms appear to be *Placunopsis* (*socialis* ?) and a very small *Ostrea*. No Plants. . . 0 ft. 6 in.	0	6

	ft.	in.
18. (*f*) Dark blue clay freshly cut, light blue or light green dry, with *vertical plants*. Lower part very ferruginous, shading off into limestone below, by shaley ferruginous layers 3 ft. 0 in.	3	0
All the beds excepting 17 (*e*) contain plant remains. Any of the beds may vary in thickness, but the aggregate thickness (16 feet) remains the same.		
19. Estuarine Limestone. (*a*) Oyster-bed in friable ruddy limestone or hard marl; oysters most abundant at top :—*Cyprina, Modiola, Mytilus, Ostrea, Rhynchonella* (large) 1 ft. 9 in.		
(*b*) Blue-hearted limestone with :—*Natica pyramidata, Astarte, Cardium, Pholadomya heraulti, Placunopsis socialis, Ostrea* (rarer), *Rhynchonella* (*Burmirhynchia dromio*, S. Buck.), *Acrosalenia* . . . 1 ft. 3 in.		
(*c*) Thin layer more like (*a*). . . . 0 ft. 6 in.	3	6
Kind of mud parting.		
20. (*d*) Hard blue limestone (required blasting), very few fossils to be got except at the surface, where rather plentiful for some 3 inches :—*Ostrea, Rhynchonella, Acrosalenia* 1 ft. 6 in.		
(*e*) Variable bed, most irregular, principally argillaceous limestone, but in places much impregnated with iron, or even an ironstone. Lower 8 inches perhaps best described as a calcareous clay :—*Cyprina loweana, C. muciformis* ?, *Ostrea sowerbyi* (most abundant in parts), *Placunopsis socialis, Rhynchonellae* (mostly crushed), (*Burmirhynchia patula*, S. Buck. here ?). . . . . 1 ft. 4 in.	2	10
Oyster layer.		
21. Below Limestone. (*a*) Purplish clay with *vertical plant markings* and *drift wood*, most irregular in thickness, as much as from 6 inches to 3 feet 5 inches.		
(*b*) Ruddy basement layer forming a nearly straight line, a well-defined red line with bed below	3	5
Inferior Oolite. 8 feet 6 inches.		
Northampton Sand. / Lower Estuarine Beds. 22. White Sand, a little ruddy in places, with *vertical plant markings*. Variable in thickness owing to irregular junction with Variable Beds below, but where other measurements taken . 1 ft. 0 in.	1	0
Inferential Unconformity.		
Northampton Sand. / Lower Estuarine Beds. 23. Variable Beds (Estuarine). Purplish, ferruginous sand with *vertical plant markings* in the upper part. Lower down, wood in horizontal position, and some rather large pieces at various angles. Variable thickness up to 5 ft. 0 in.	5	0
Northampton Sand. / Lower Estuarine Beds. 24. Ironstone variable in colour from dark green to rich red, also varying in thickness owing to the mutual encroaching of 23 and 24 . . .	2	6
Upper Lias.		
25. Blue clay, hard and micaceous near junction with ironstone; no junction-bed of phosphatic or bored nodules, and no sign of unconformity; indeed, ironstone layers occur in the clay itself some distance down. No fossils observed . .	20	0

GENERAL REMARKS ON THE SECTION.

1. Glacial Beds. No "Drift" was observed in the most northerly part of the cutting, but between bridges 2 and 3, going

southwards, it gradually came in and at and near bridge 3 became a pronounced feature, consisting there in large part of displaced, contorted and mixed material of all the regular beds above the Great Oolite Limestone, i.e. Great Oolite Clay, Forest Marble, and Cornbrash. Thereafter, southwards to Roade station, the cutting may be considered as consisting of Chalky Boulder Clay and Great Oolite Limestone only, though here and there other local material was so predominant as to suggest that it might be in situ. This was particularly the case between bridges 4 and 5, where a long, regular line of Cornbrash blocks occurred,[1] and not far from these was an exposure of what looked like definite Forest Marble without admixture, but across the line, on the western side, just opposite, only Drift beds occurred over the Great Oolite Limestone, but with Cornbrash boulders at all angles and various levels. It was almost a gravel in places, there were so many stones in it. Great Oolite boulders were also found in Chalky Boulder Clay a little further northwards on the western side of the line.

Great Oolite Limestone. The names given to divisions of this formation are impressionist ones, appropriate for this particular section and district, but not claimed to be the best for a general Northamptonshire sequence, which has yet to be worked out. Many more fossils than those recorded were found (collected by one of the engineers), but are omitted where the horizon or bed in which they occurred is in doubt.

7. Plant Beds. This horizon (or feature) is rarely to be identified elsewhere.

9. Coral Bed. Coral is not particularly rare in the Great Oolite Limestone, but this bed at Roade is more definitely located in the sequence and can be detected over a larger area around than is usually possible.

10. Intermediary Bed. This peculiarly unfossiliferous layer was also well exhibited in a section at Roade village, showing that it was not just an accidental occurrence.

11. Terebratula Bed. This appears to be the particular horizon in this neighbourhood of certain large *Terebratulae* which in the past have commonly been quoted as *T. maxillata* and later as *T. intermedia*, but which Mr. Buckman has recently named *Kutchithyris* aff. *circumdata* Desl. Presumably it is also the horizon, in this neighbourhood, of *Ornithella digona* Sow., and a more delicate, that is less bulky, form of *Kutchithyris* ? which the late Mr. J. F. Walker identified as his *Terebratula intermedia* var. *langtonensis*. This suggestion as to horizon is made because at Wootton, 2½ miles northwards of Roade cutting, the two

[1] In April, 1892, Mr. George Smith, of Roade, took me to see these Cornbrash blocks near to bridge 5. He said that when the railway was being made fifty to fifty-five years before, Mr. Rawlinson (afterwards Sir Robert Rawlinson) lived at Roade and often used to take geologists to get fossils and see "the large blocks of stone brought by ice".

fossils named occur together below a Coral Bed and above the Nerinaea Bed, that is in the same relative position as the Roade Terebratula Bed.[1] Mr. Buckman, however, tells me that the form described above as *O. digona* is his *Ornithella digonoides*,[2] which he thinks occurs in the Cream Cheese Bed of Ardley section and in the Herbyleigh Beds (Weymouth).

13. Nerinaea Bed. This is a definitely recognizable bed over a large area. The *Terebratulae* here are also large like in the Terebratula Bed, and have in the past been usually described as *T. maxillata*, now known as *Epithyris bathonica* S. S. Buck. ? *Rhynchonellae* occur sparingly, but are not of the kind occurring so abundantly in the Rhynchonella Beds below. Mr. Buckman suggests that this bed 13 represents beds 5 to 21 of the Ardley Section,[3] which seems very probable.

14–15. Unconformity. This point in the sequence is so definitely an upper limit to the *Rhynchonella varians* group of brachiopods that without physical evidence an unconformity may be inferred. The missing beds may be supposed to be 22 to 27 of the Ardley section, and perhaps also a good part of 28 to 35.[3]

15. Rhynchonella and Pholadomya Beds. In some places the *Rhynchonellae* in these beds are accompanied by an almost equal number of small *Terebratulae* (*Epithyris* ?). These beds doubtless correspond to those classed as Upper Fullonian by Odling.[3]

16. Upper Estuarine above Limestone [Neaeran Beds]. These beds so accurately represent in character and position the beds named Neaeran and classed as Lower Fullonian in Odling's paper that they may be regarded as the same. No *Neaerae* were found in them at Roade, but this may be partly accounted for by their not being sufficiently looked for, as *Naeara ibbetsoni* is quite common in similar and similarly situated beds in other parts of Northamptonshire.

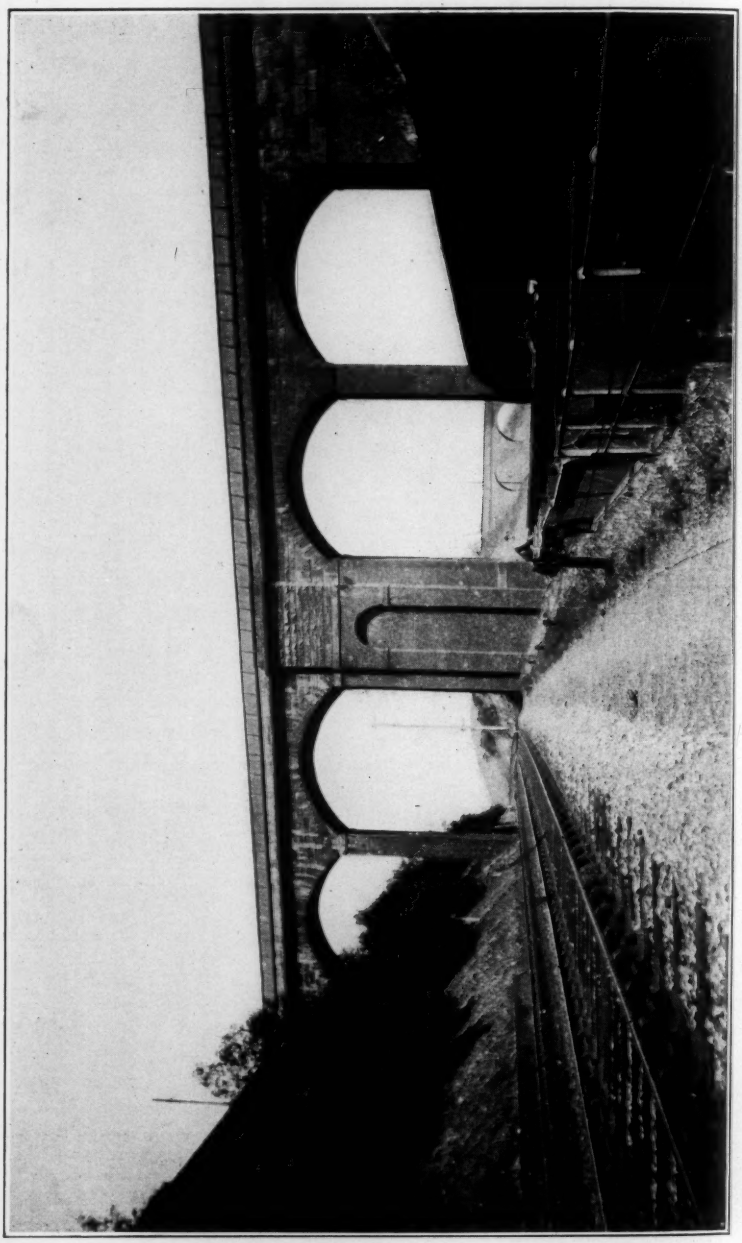
17. Placunopsis Bed. *Placunopsis* is a common fossil throughout the Upper Estuarine Series, but is nowhere so abundant as in this bed No. 17, a bed which appears to have its counterpart in character, though not exactly in position, in the Neaeran Series of Oxfordshire (see Walford, *On some New Oolitic Strata in North Oxfordshire* : *Buckingham Advertiser* Office, 1906).

19, 20. Upper Estuarine Limestone—Chipping Norton Limestone ? *Rhynchonellae* are sporadically abundant in the Estuarine Limestone, that is to say, when they occur they are

[1] See Report of Excursion to Northamptonshire in 1891, *Proceedings of Geologists' Assoc.*, vol. xii, pp. 177–8.

[2] *Palæontologia Indica*, N.S., vol. iii, Memoir 2, Brachiopoda, by S. S. Buckman, F.G.S.

[3] Ardley Section, see "The Bathonian Rocks of the Oxford District", by M. Odling, M.A., B.Sc., F.G.S. : *Q. J. Geol. Soc.*, vol. lix, 1913, p. 484.



ROADE CUTTING. SOUTH SIDE OF BRIDGE 2.

To face p. 217.]

likely to be abundant but perhaps more often are absent or rare. In the former case the dominant forms are rather bulky specimens of *Burmirhynchia* of S. S. Buckman; indeed, the figured specimen of *Burmirhynchia dromio* S. S. Buck. in *Palaeontologia Indica*, plate xv, 27 *b*, came from this bed at Roade.

This particular bed or set of beds in the Upper Estuarine Series was first given the distinctive name "Estuarine Limestone" by me because it showed itself conspicuously as a good water-bearing bed at a number of places and could be traced over a large area of Northamptonshire. It is always (?) succeeded upwards by beds containing *plant remains* in abundance, with quite often *Neaera ibbetsoni* (hence "NEAERAN BEDS"); so the idea has long been present in my mind that the Upper Estuarine Limestone of Northamptonshire represented the Chipping Norton Limestone of Oxfordshire, if not exactly the specific horizon or time, the occurrence of similar conditions. This idea was strengthened by Mr. Buckman's remarks on the *Rhynchonellae* from Northamptonshire and Ardley (Oxf.), for he has recently said (litt.) "the similarity (rather identity) of Rhynchonellas in the Estuarine Limestone of Norths. and the Bird's Nest Rock of Ardley and top of bed *l* shows that they can be correlated as contemporaneous". Consequently if genuine proof existed that the beds at Ardley were really Chipping Norton Limestone, as stated to be in Odling's paper, the identity of the Northamptonshire Upper Estuarine Limestone and the Chipping Norton Limestone would appear to be established.

The problem, however, is not so simple as this would indicate, for Mr. Buckman further says with regard to Ardley that there is a definite *Rhynchonella* sequence, say 1, 2, 3, there in the so-called "Chipping Norton Limestone" which is found in the Estuarine Limestone of Northamptonshire but at three rather widely separated places. From considerations entirely unconnected with the question of a brachiopod sequence I should consider it extremely likely that the Estuarine Limestone does occur at different horizons (time intervals) in the Upper Estuarine Series of Northamptonshire, for *plant beds below* it vary in thickness from 0 feet to 25 feet.

It is not expedient to carry this discussion further in a paper devoted primarily to one section in Northamptonshire with a few references to one in Oxfordshire, but it was considered worth while calling attention to the correlation suggested.

21. BELOW LIMESTONE. Not infrequently definitely marine beds *alone* occur below the Estuarine Limestone and perhaps should be classed with the latter, although not limestones, but uncompacted oyster-beds or even sandy beds with oysters.

22. WHITE SANDS. These are usually classed with the Northampton Sand, but evidence is accumulating to justify a separation from the latter.

EXPLANATION OF PLATES X AND XI.

PLATE X.—Diagrammatic section along Roade Cutting. Horizontal scale 10 inches to 1 mile, vertical scale $\frac{1}{8}$ inch to 10 feet. It may be observed in the diagram that the dip of the loop line commences near to bridge 4, and that at bridge 2, where the older and newer lines diverge, the loop line for Northampton is 20 feet below the Blisworth line. The levels were kindly supplied by Col. H. A. Hull, District Engineer.

PLATE XI.—Roade Cutting, south side of bridge 2, showing divergence of the lines, beyond the bridge. On the right is seen the strutting of the deepened part of the cutting on the Northampton line.

The Avonian of Cannington Park, near Bridgwater, Somerset.

By F. S. WALLIS, Ph.D., F.G.S. (Bristol Museum).

I. INTRODUCTION AND PREVIOUS WORK.

THIS small, though extremely interesting area of Carboniferous Limestone is situated about 4 miles north-east of Bridgwater and $\frac{3}{4}$ mile north-east of the village of Cannington.

For several reasons it has attracted a large number of workers. Fossils are scarce (at first the mass was thought to be unfossiliferous), and hence for a long time the " Devonian or Carboniferous " question of age was a bone of contention. Also, the final acceptance of its Avonian age showed that productive Coal Measures were probably deposited in the area between the Mendips and the Quantock Hills.

Since the introduction of Vaughan's zonal methods to the study of Avonian rocks the area has attracted little attention, and the aim of the present work is to correlate the mass with the typical Avonian sequence of the Bristol area.

In consequence of the large number of exposures made during the war for the extraction of barytes, and also owing to the fact that these are now being rapidly filled in, the present time seemed opportune to carry out this study.

The area is included on Sheet No. 295 of the New Series and Sheet No. 21 of the Old Series (one-inch) maps of the Geological Survey and Sheets 49 N.E. and 50 N.W. (Somerset) of the 6-inch O.S. Maps.

Previous research may be summarized as follows :—

1. 1816. *Horner, L.*, " Sketch of the Geology of the South-western Part of Somersetshire " : *Trans. Geol. Soc.*, Ser. I, vol. iii, pp. 365–6.

   The author states that the limestone mass is of transition (Devonian) age and may be compared with the Plymouth limestones. He does not give any palæontological evidence in support of this view. The occurrence of barytes is noted.

2. 1824. *Buckland, W.*, and *Conybeare, W. D.*, " Observations on the South-western Coal district of England " : *Trans. Geol. Soc.*, Ser. II, vol. i, p. 264.

The writers mention that the Mountain limestone re-emerges in Cannington Park. They give no reasons for their deduction. Thus as early as 1824 a Carboniferous age was advocated for this limestone mass.

3. 1838. *Williams, D.*, " On some Fossil Wood and Plants discovered low down in the Grauwacke of Devon " : *Rep. Brit. Ass.* 1837 (Liverpool), *Trans. of Sections*, p. 94.

In a vertical section of the strata of North Devon and West Somerset, the Cannington Park Limestone is placed below the Foreland Sandstones, i.e. at the base of the Devonian.

4. 1839. *De la Beche, Sir H. T.*, " Report on the Geology of Cornwall, Devon, and West Somerset " : *Mem. Geol. Survey*, pp. 55–6.

De la Beche remarks that " the limestone is so surrounded by red sandstone that its clear connexion with the rocks of the Quantock Hills cannot be traced satisfactorily ". He was inclined, however, to treat it as a Devonian limestone.

5. 1841. *Phillips, J.*, " Palæozoic Fossils of Cornwall, Devon, and West Somerset " : pp. 142–3.

Cystiphyllum damnoniense and *Millepora similis* are recorded, and the age is given as equivalent to that of the Ilfracombe Beds. Confirmation of the occurrence of either of these fossils has not been obtained.

6. 1842. *Williams, D.*, " On as much of the Transition or Grauwacke System as is Exposed in the Counties of Somerset, Devon, and Cornwall " : *Proc. Geol. Soc.*, vol. iii, p. 115.

The writer re-affirms his previous opinion (3) and places the limestone at the base of the Devonian.

7. 1843. *Buckland, Dr.*, " Notice of Perforations in Limestone " : *Rep. Brit. Ass.* (Manchester), 1842, *Trans. of Sections*, p. 57.

The small, deep, irregularly rounded holes on the surface of the limestone are here attributed to snail action.

8. 1851. *Baker, W.*, " Geology of Somerset " : *Proc. Som. Arch. and N.H. Soc.* for 1849 and 1850, p. 129.

The occurrence of crinoids and corals in the Cannington Park Limestone is here definitely affirmed.

9. 1853. *Baker, W.*, " The Cannington Park Limestone " : *Proc. Som. Arch. and N.H. Soc.* for 1852, pp. 125–31.

Relying on some additional palæontological evidence which he had discovered, Baker definitely determines the age of the mass to be Lower Carboniferous. He also states that according to some MS. notes of the Rev. D. Williams, this author raised the age from Lower to Middle Devonian.

10. 1855. *Payne, J. H.*, " Geology of the Quantocks " : *Proc. Som. Arch. and N.H. Soc. for* 1854, p. 105.

Mention is made of the fact that the rock is lithologically different from any Quantock limestone. The author believes that it will be placed finally amongst the Carboniferous rocks.

11. 1867. *Etheridge, R.*, "On the Physical Structure of West Somerset and North Devon": *Q.J.G.S.*, vol. xxiii, 1867, pp. 579–81.

In spite of the evidence of previous researches, the author states that in lithological, palæontological and structural characters the mass strongly resembles the Torquay limestones of South Devon and the Adscombe and Stowey limestones of the Quantocks. He illustrates his view by a horizontal section (op. cit., p. 584).

12. 1871. *Bristow, H. W.*, and *Woodward, H. B.*, "Remarks on the Prospects of Coal to the South of the Mendips": Geol. Mag., 1871, p. 504.

Though the paper chiefly deals with the possibility of coal being found south of the Mendips, the authors definitely state that the limestone of Cannington Park is of Carboniferous age.

13. 1872. *Perceval, S. G.*, "On the Limestone at Cannington Park, near Bridgwater": Geol. Mag. (Letter), 1872, pp. 94–5.

After examining and naming the corals of several collections, the author states that there is no doubt as to the Carboniferous age of the mass.

14. 1876. *Tawney, E. B.*, "On the age of the Cannington Park Limestone and its Relation to the Coal Measures south of the Mendips": *Proc. B.N.S.*, New Ser., vol. i, pt. iii, pp. 380–7.

The writer gives a history of the discussion as to the age of this inlier and quotes additional palæontological evidence in favour of its Carboniferous age.

15. 1876. *Tawney, E. B.*, *Rep. Brit. Ass.* (Bristol), 1875, *Trans. of Sections*, p. 82.

This is a short summary of the evidence published in (14).

16. 1876. *Woodward, H. B.*, "Geology of East Somerset and Bristol Coalfields": *Mem. Geol. Survey.*

The memoir contains several allusions to the Cannington Park inlier, and the evidence settling its Carboniferous age is summarized (op. cit., p. 26).

17. 1879. *Champernowne, A.*, and *Ussher, W. A. E.*, "Notes on the Structure of the Palæozoic Districts of West Somerset": *Q.J.G.S.*, vol. xxxv, 1879, pp. 546–7.

The limestone mass is regarded as unquestionably of Carboniferous age. Some new fossil evidence is brought forward and numerous dip determinations are given. From the latter figures the authors believe that the beds form an anticline, the axis of which trends in a north and south direction.

18. 1908. *Ussher, W. A. E.*, "The Geology of the Quantock Hills": *Mem. Geol. Survey*, pp. 32–8.

The limestone mass is here tentatively placed in the *Seminula* zone. The author believes that the inlier is faulted against the Middle Devonian rocks on the south by a Pre-Triassic disturbance.

19. 1910. *Ussher, W. A. E.*, "Geology in the Field": *Geol. Ass. Jubilee Vol.*, p. 863.

The author simply mentions the "cherts, shales, and limestones" of the Cannington Park area.

20. 1916. *Kendall, Professor P. F., Handbuch der regionalen Geologie.* "The British Isles," p. 143.

In a footnote the limestone of Cannington Park is referred to the S_1 subzone.

Henceforth all the above papers are referred to by their serial number placed in parentheses.

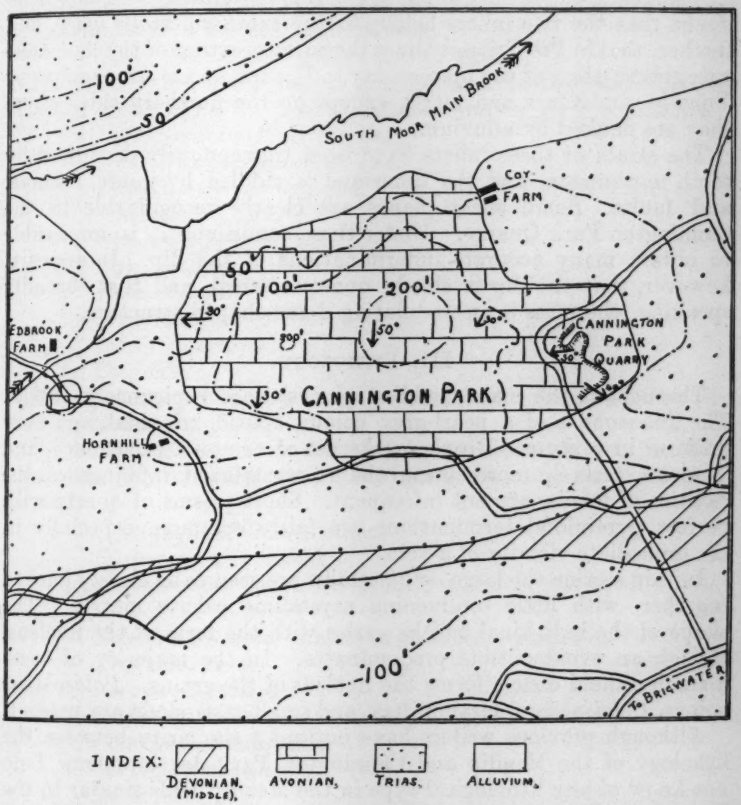


FIG. 1.—Geological map showing the Avonian outcrop at Cannington Park, Som. Lines are based on maps of the Geological Survey. Scale, 6 in. = 1 mile.

II. General Physical and Geological Structure.

The limestone mass of Cannington Park forms a prominent nearly isolated hill with a maximum height of 264 feet. On its northern side it rises steeply from the alluvial flats of the River Parrett and its tributary, whilst on the southern flank the hill gradually merges into the minor spurs of the Quantocks. The scenery is similar to

that of the Mendips; the prominent limestone crags and thin soil being in marked contrast to the neighbouring Quantock Hills.

The Carboniferous limestone mass really consists of two inliers separated by a strip of Trias. The larger inlier approximately coincides with the area known as Cannington Park, whilst the smaller one is bisected by the road from Hornhill Farm to Edbrook Farm. Maximum measurements of the larger inlier give 990 yards in a north and south, and 1,370 yards in an east and west direction. The smaller inlier is only about 100 yards in diameter. There is no doubt that the two inliers belong to the same limestone mass, and further, that in Pre-Triassic times the surface extent of the limestone was greater than at the present day. The inliers are surrounded by Triassic sandstones and marls, except on the northern side, where they are flanked by alluvium.

The strata of these inliers have been tremendously disturbed by earth movements, and the limestone is riddled by joints, fissures, and faults. Small shear planes are clearly recognizable in the Cannington Park Quarry. Under these conditions it is impossible to obtain many accurate determinations of the dip. It appears, however, that the dip is chiefly qua-qua-versal, and that, broadly speaking, the mass is an undulating dome-shaped structure.

III. Lithology.

Throughout the mass, bedding planes are conspicuously absent. The limestone is of a pearl-grey colour, oolitic, crinoidal, and very uniform in texture. Ripple marks are of common occurrence, and "calcite nests", representing the re-crystallized infillings of the cavities of fossils, are not infrequent. Short prisms of quartz with perfect pyramidial terminations are fairly common, especially in the immediate vicinity of a vein.

In thin section the large oolitic grains are seen to be closely packed together, with little intervening crystalline calcite matrix. The shape of the individual ooliths varies with the form of the nucleus, though an ovoid outline predominates. In the majority of cases a small crinoid ossicle forms the nucleus of the grains. *Palaechinus* spines, *Calcisphaera*, foraminifera, and small gastropods are present.

Although previous writers have noticed a similarity between the lithology of the Mendip and Cannington Park developments, I do not know of any lithological type in the Mendip Hills similar to the dove-grey coloured rock of this area.

Veins of barytes are very common. They were extensively worked during the war for emergency purposes, but little is extracted at the present time. The veins are very irregular and occupy fissures, joints, and fault planes. In each case the crack appears to have been first lined with calcite. This was followed by the deposition of barytes and finally a small amount of copper. The latter element now appears in the form of the oxide (cuprite) or the carbonate (malachite). There is also a certain amount of vein-breccia, cemented

by calcite or barytes. All the veins occur at a well-defined level (about 160 feet O.D.), and were evidently deposited by the marginal waters of the Triassic seas.

IV. Fauna.

Fossils are exceedingly scarce.

The following have been identified by the writer :—

Lithostrotion martini E. and H.

This is by far the most abundant fossil. There is a large amount of variation both in the diameter of the corallites and in the number of dissepiments in the extra-thecal area.

Near *Carcinophyllummendipense* Sibly.

The Cannington Park variety is larger and has a greater number of septa (generally 45). The thick inner wall is very prominent.

Syringopora distans Fischer.
Near *Cyathophyllum* ϕ Vau.
Lithostrotion basaltiforme Phill. var. *bristolense* Vau.
Productus θ Vau.
Seminula ficoidea Vau.
Calcisphaera.
Palaechinus.
Foraminifera.
Small Gastropods.
Crinoids.

The existence of such a faunal assemblage as that enumerated clearly indicates an S_1 age.

The following have been recorded by previous writers, but their occurrence has not been confirmed during the course of the present research :—

Cystiphyllum damnoniense.
Syringopora ramulosa.
Lithostrotion irregulare—this is probably the small variety of *L. martini.*
Productus elegans (small) or *Productus punctata.*
Productus cora.
Atrypa reticularis.
Orthis sp.
Conocardium aliforme.
Millepora similis.
Bivalves.

The best fossil localities are :—

(1) Western and north-western face of the Cannington Park Quarry.
(2) Old Quarry immediately south of Coy Farm.
(3) Limestone crags at the top of the hill (especially good for weathered fossils).

V. Physiographical Conditions of Deposition.

On account of the isolation and small surface extent of this limestone mass it is impossible to draw any definite conclusions regarding

the physiographical conditions under which the sediments were laid down.

In North Devon there is evidence of deposition in β (Upper Pilton) and D_3 (Codden Hill Beds) times only. Thus during the greater part of Avonian times, North Devon was either a land area or the beds that were originally deposited have been removed by faulting or erosion, or are now concealed from view. If the first supposition is correct the Cannington Park area would have been near the southern shore of Vaughan's " S.W. Channel " (*Rep. Brit. Ass.* (Manchester), 1915, *Trans. of Sections*, pp. 429–31), and hence we should find evidence of shallow water marine conditions. This evidence is seen in the remarkably persistent and uniform oolitic nature of the rock, and in the abundance of ripple markings. The fauna is of a scanty though marine nature, and the depth of water was evidently unsuitable to an abundant standard marine life, such as occurs in the S_1 sub-zone of the Mendip Hills.

Deposition was sufficiently continuous to prevent the formation of well-marked bedding planes, and general conditions must have borne a close similarity to those under which the *Caninia* oolite of the Bristol District was laid down.

VI. Relation with Neighbouring Strata.

Unfortunately the actual junction between the Avonian of Cannington Park and the Middle Devonian strata of the Quantock Hills is everywhere masked by the Trias.

The Cannington Park mass must be either faulted against, or unconformable to, these Devonian rocks. As pointed out by Ussher (18, p. 34), in the latter case we should expect to find marginal conditions of sedimentation within the mass. Though the deposits are of shallow water origin, there are no signs of actual shore-conditions of deposition.

As the Triassic rocks are undisturbed we can only infer that the mass has been faulted against rocks of Middle Devonian age by a pre-Triassic disturbance. The very disturbed nature of both the Avonian and Middle Devonian beds supports the conclusion of extensive faulting in the area. It is unfortunate that such a small portion of the lateral and vertical extent of the Avonian beds deposited south of the Mendips is now exposed. Its extent and nature would throw much light on this area in particular and Lower Carboniferous geography in general.

VII. Conclusions.

1. The Cannington Park limestone is of Avonian (S_1) age.

2. The deposits were laid down under shallow-water marine conditions, probably near the southern shore of Vaughan's " S.W. Channel ".

3. Though the evidence is admittedly inconclusive, it is probable that the mass was faulted against the Middle Devonian strata by a pre-Triassic movement.

I wish to tender my best thanks to Professor S. H. Reynolds, M.A., Sc.D., for kindly reading through the MS.; to Mr. St. George Gray, F.S.A., who kindly allowed me to examine specimens from Cannington Park now housed in the Taunton Museum; to Mr. W. G. Smith for loan of several specimens; to Mr. G. Hammick for permission to examine the area; and to Mr. P. T. Parsons for information regarding the uses of barytes.

On some Cornish Veinstones illustrating the close connexion between Igneous Intrusion and Deep Vein Filling.

By E. H. Davison, B.Sc., F.G.S.

IT is now generally accepted that there is no essential difference between igneous intrusion and the deposition of the minerals which fill the deep veins. Both igneous rocks and deep veins were formed from magmatic material, their differences being due to successive differentiation and not to difference in origin.

This view has been clearly elaborated by Rastall in his recent treatise on Metalliferous Deposits [1] and also by Spurr in his book on the Ore Magmas.[2]

In the following notes the author wishes to draw attention to the clear way in which this relation is illustrated in Cornish rocks and veinstones.

In the first place, there are many instances of the presence of metallic minerals as constituents of igneous rocks, the following table giving the chief occurrences :—

METALLIC MINERALS IN IGNEOUS ROCKS.

Locality.	*Rocks.*	*Metallic minerals.*
Ponsanooth.	Granite.	Mispickel.
Constantine.	,,	,,
Carn Menelez granite mass.	,,	Cassiterite distributed through granite near lode bearing areas.
St. Michael's Mount.	Greisen and pegmatite.	Cassiterite, wolfram, chalcocite.
Cligga Head.	Greisen.	Cassiterite, wolfram, mispickel.
	Pegmatite.	Mispickel, wolfram.
Porthmeor Cove.	,,	Cassiterite.
Trewavas Cove.	,,	Mispickel.
Belowda Beacon.	Greisen.	Wolfram and cassiterite.
Kit Hill.	,,	,,
Hemerdon.	,,	Wolfram, cassiterite, mispickel.
Parbola Mine.	Quartz-porphyry.	Cassiterite.
Rosewarne Mine.	,,	,,
Relistan Mine.	,,	,,
Wherry Mine.[3]	,,	,,
St. Dennis Consols.[3]	,,	,,
Wheal Badnick.[3]	,,	,,

[1] Rastall, *The Geology of Metalliferous Deposits*, 1923.

[2] Spurr, *The Ore Magmas*, 1923.

[3] Reported by J. H. Collins.

Locality.	*Rocks.*	*Metallic minerals.*
Creeg Brawse Qy.	Quartz-porphyry.	Cassiterite.
Royalton Qy.	,,	,,
St. Agnes Beacon.	Granite.	,,
	Quartz-porphyry.	,,
Wheal Busy.	,,	Mispickel, cassiterite.
Carn Brea.	,,	Mispickel, cassiterite, galena.
Bolenowe Moor.	,,	Cassiterite.
Tuckingmill Qy.	,,	,,
Hangman's Barrow.	,,	,,

The above occurrences are of metallic mineral disseminated through the rock, and not merely of veins traversing the rock.

The most conclusive evidence is, however, found in those instances where the vein filling is intimately intergrown with material of undoubted magmatic origin. Several examples of this type have been observed, the following being the clearest.

Veinstone from South Crofty Mine, New Cook's Section.

This vein occurs in a slate in a stope just above the 220 fathom level. The metallic minerals are wolfram, mispickel, and stannine, while the gangue minerals include quartz and chlorite.

The wolfram occurs in large phenocrysts, surrounded by a coarsely crystalline aggregate of the other minerals, the texture resembling that of a pegmatite. Intergrown with the veinstone minerals proper are patches of fine-grained granitic material composed of clear quartz and pink orthoclase.

Penlee Quarry, Newlyn.

This quarry in the greenstone, or more correctly epidiorite, shows a vein of mispickel and pyrite traversing the rock. The vein is filled by brecciated fragments of greenstone cemented by a mixture of granitic material, which is intimately intergrown with a mixture of quartz, pyrite, and mispickel. The granitic material is composed of clear quartz, pink felspar, and a little muscovite, and shows no definite boundary with the more typical vein filling which it sometimes includes.

Veinstone from Gwennap United Mine.

On the waste heap of Gwennap United Mines the writer recently found a specimen showing a vein traversing the clay slate, which was tourmalinized. The vein showed banded texture, the outer band on either side consisting of quartz, muscovite, tourmaline, and kaolinized felspar with cassiterite and some copper mineral which had yielded a green stain, while the central part of the vein was filled by finer grained quartz with muscovite and tourmaline. The slate on either side showed intense tourmalinization at the immediate contact.

Veinstone from Mulberry Mine, Withiel.

This vein is about 2 inches wide, and is one of the numerous veins which traverse the clay slate in the Mulberry openwork. The vein filling is chiefly quartz, but there is in addition a good deal

of sericitic mica and kaolin. The metallic mineral is cassiterite in fairly coarse crystals.

Veinstone from Wheal Fortune, Breage.

This is another instance of a number of parallel veins cutting the clay slate, so close together as to form a stock-work. The veins are mostly very narrow, and consist of quartz, white mica, gilbertite mica, and cassiterite. Some of the larger veins show felspar.

Veins in Clay Slate, Castle an Dinas, St. Columb.

The author in a previous paper [1] described the occurrence of fine veins penetrating the clay slate at Castle an Dinas Wolfram mine. These veins are composed of quartz, gilbertite, and tourmaline, with cassiterite, and ran from the granite into the slate.

Veinstone from Tincroft Mine.

This veinstone consists of quartz, orthoclase, chlorite with wolfram, mispickel, chalcopyrite, blende, and cassiterite. The minerals are intergrown, and there are instances of mispickel enclosing quartz, quartz enclosing wolfram and mispickel, orthoclase enclosing wolfram, and wolfram penetrating orthoclase; in fact, the texture is that of a moderately coarse-grained pegmatite.

Pegmatite, Williams Shaft, Dolcoath Mine.

At the bottom of Williams Shaft, Dolcoath, a pegmatite vein was seen to traverse the granite, which had an unusual composition. The rock was fairly coarsely crystallized, and was composed of quartz, felspar, much of it albite, lithia mica with much red garnet, and crystals of dark cassiterite up to a quarter of an inch across. Microscopic examination showed that the rock also contained andalusite.

The way in which the vein fissure is filled in the specimens described above, partly by ordinary vein minerals and partly by granitic material, confirms the idea that the agents filling the lodes were of magmatic origin, while the common occurrence of metallic minerals as constituents of igneous rock shows that they were present in the original magma.

In the author's view the sequence of events as shown by Cornish evidence may be briefly stated as follows:—

Intrusion of magma which on consolidation becomes granite.

Residual magma containing almost all of the volatile constituents of magma.

On consolidation this forms either

Pegmatite	or	Aplite.
Rich in volatiles and water with some metallic minerals.		Poor in volatiles and water.

Residual magma very rich in volatiles, metallic minerals, and water.

On consolidation forms mineral veins.

[1] Davison, "The Geology of Castle an Dinas and Belowda Beacon": *Proc. R.G.S.C.*, 1919.

Fossil Ostracoda and their use in Stratigraphical Research.

By Edgar A. Merrett, M.Sc., F.G.S.

I. Introduction.

ALTHOUGH much work has been done in connexion with fossil Ostracoda, little attempt seems to have been made to correlate the results arrived at, and, in consequence, much of the value of the work of such writers as Rupert Jones, R. S. Bassler, E. O. Ulrich, etc., is in danger of being overlooked. The following is an attempt to collect together in an orderly manner the work of these and other writers, and at the conclusion it will be indicated by reference to the classification of the Purbeck Beds in the Vale of Aylesbury, the use which may be made of these minute fossils to settle questions of great geological importance in cases where no other evidence is forthcoming.

C. D. Sherborn, whose name is associated with that of Rupert Jones in several works on Ostracoda and other Microzoa, hints at the need and possible value of such work when he says, "What is really wanted, is careful collecting from some well-known section, or series of sections, of any geological formation, and this would be of greater importance than the casual description of various species taken at random from many localities, though the latter is, of course, a very necessary work." R. S. Bassler remarks that Ostracoda are of "considerable value in stratigraphical correlation, and throw light on palæogeographic problems up to the Pennsylvanian, though their value in this respect seems much diminished in later times", whilst speaking generally of the group Entomostraca, Rupert Jones states, "If we had only these little fossils whereby to form an opinion of the probable conditions under which clays, sandstones, and limestones were formed in the long past eras of this planet, we should have, in nearly every case, ample evidence of the history of every bed of mud, silt and shell sand in which these minute Entomostraca can be found." In illustration of this statement he gives a lucid description of the varying conditions from Silurian times onwards during which Entomostraca existed as scavengers of seas and lagoons. In the same connexion, G. S. Brady, who concentrated on the more recent forms, significantly remarks, "My belief is, therefore, that those strata which exhibit such very abundant and closely packed remains of the smaller Cypridæ and Citheridæ have most likely been formed in shallow brackish lagoons, or at the mouths and deltas of rivers."

Thus the chief authorities on this group of fossils are agreed that they often prove of very considerable value to the stratigraphist who is prepared to consider their claims upon his attention.

II. Geological Significance of Ostracoda.

Before proceeding to discuss the affinities and natural history of the Order Ostracoda, it will be desirable to examine in detail the

claims which the minute creatures comprising the order have to the study of a geologist.

In the first place, remains of Ostracoda are found in rocks of all ages from the Ordovician onwards. At one time certain forms, even in Cambrian rocks, were included in this order, but these have since been shown to be "bivalved Phyllopods" (branchiopods).

Coupled with this persistence from the time of the deposition of almost the earliest rocks to the present day is the fact that they are found in rocks of all types. Throughout the ages they have been ubiquitous in distribution and indiscriminate in the kind of water or sediment in which to live. Though most abundant in limy sediments, they are also abundant in highly siliceous strata, in all kinds of shales and even in relatively coarse beach-worn sandstone. Perhaps one of the most important reasons for a careful study of this group is that freshwater Ostracoda are frequently the only animal remains in considerable thicknesses of continental deposits. Their presence in such deposits may perhaps sometimes be explained as due to the distribution of their minute carapaces by wind action, but more frequently the masses of these fossils could have had no other origin than burial in situ. In this connexion, it is only necessary to observe the millions of water-fleas existing in almost any wayside pool at the present day to realize the possibility of the formation of solid masses of their remains on the evaporation of the water, or the sudden infilling of the pool by solid matter. The importance of the presence of these remains in rocks with such varied origins, together with the difference in form shown by those of marine and those of freshwater origin, was shown by Jones and Kirkby in their work on the Ostracoda of Carboniferous age.

Not only are fossil Ostracoda found in rocks of all types and of all ages, but, when found, they are often very abundant. In this connexion Rupert Jones remarked, "Flake after flake of black clay, once mud, may easily be picked by the hand in the Isle of Wight in cliffs some miles in extent from beds of shale two hundred feet thick, every surface being thickly coated with the shells or carapaces of these minute creatures." So common are they in certain beds, e.g. the Cypridea Beds in Durlston Bay, that they occur in swarms to the virtual exclusion of other material, and thus claim to rank among the "rock formers". Describing this rock, Frederick Chapman remarks, "In thin slices under the microscope the rock is seen to consist of myriads of valves of Ostracoda, closely packed together; the interstitial mud being reduced to a minimum merely serving to fill up the hollows between the shells." Their small size and impersistent deposition, however, restrict their rock-forming capacities to thin beds. Other examples of Ostracoda which play the rôle of rock-formers are the *Leperditia* and *Beyrichia* in rocks of Ordovician and Silurian age, and *Cypridea* in the Wealden. Where they abounded in the old fluviatile and estuarine muds which have become the Wealden strata, they gave up the lime of their shells to

the mud, making numerous layers here and there in the thick clays into hard bands of rock.

Thus, in individual development they exceed almost every other group. Bassler, after his excellent review of the development of Palæozoic forms in his paper on " The Stratigraphic significance of Ostracoda ", used this fact to point out the decreasing value of Ostracoda to the stratigraphist in rocks later then Palæozoic in age. That this is not entirely the case, can be shown by a close study of the freshwater deposits of Purbeck age. Sherborn, in this connexion, remarks, " Among these Mesozoic Ostracoda there is one single form which seems to be an absolutely safe zonal guide—*Cypridea granulosa* (Sow.), the *Cypris fasciculata* of Edward Forbes. It has never been found anywhere but in beds of Middle Purbeck Age, and there it occurs abundantly." It is possible that further study of the group will reveal other forms which may be of similar value.

Owing to their wide distribution, the remains of these tiny creatures are often of service in showing the stratigraphical connexion between different deposits. Thus Bassler, in the work referred to above, when tracing the locus of development of the marine Ostracoda from their origin in or south of the Gulf of Mexico in early Ordovician times, then their shifting from the southern to the northern seas during the Middle Ordovician, with accompanying change in form, and later their emigration from northern into southern seas once more, shows, by remarking on the similarity of forms developed in the Baltic region of Europe and in America north of the Missouri, how a study of these fossils may be of service in the work of discriminating palæogeographic provinces and in works of detailed correlation. Hawkins suggests their use as indicators of the physical conditions under which sediments were deposited when he writes, " Perhaps the swarms of *Beyrichia* that characterize the uppermost parts of the Silurian may indicate the oncoming of Old Red Sandstone lake conditions, but closely allied forms abound in Upper Ordovician where no such prospect seems probable." In this connexion it may also be noted that the deltaic parts of the Wealden deposits are generally indicated by the remains of Cypridæ.

Having examined the claims which the group makes for consideration by geologists, it is now necessary to enumerate the difficulties encountered in the study of these creatures. Their minute size is an obvious disadvantage, for, whilst some Silurian representatives of the family Leperditiidæ reach some thirty or forty millimetres in length, the great majority of forms are one millimetre or less. Their use in the field is therefore practically negligible, as specific characters in all but a few forms can only be determined with the aid of a microscope. It is also obvious that this extreme minuteness renders the recognition of the details of variation, so essential for accurate palæontological work, extremely difficult.

Another difficulty arising from the same cause is the easy scattering of the remains of such creatures after death by waves and currents at

sea and as dust in the wind. Distinctly different types are found in the colonies swimming on the surface from those creeping at the bottom of the sea, and, as has already been pointed out, freshwater forms are distinct. The value of these distinctions as indicating the origin of the rocks in which the fossil remains are found has been referred to above, but the tendency for wide dispersal of the shells after the death of the animal makes it necessary to observe caution in deducing results from the examination of a few individuals. Dispersal at sea on waves and currents may have caused marine forms, which lived together in the same environment, to find a resting-place in deep sea ooze, or in shallow littoral deposits, whilst, by wind action, individuals may have been carried over vast areas and deposited amongst material of a totally different origin from that by which they were surrounded when alive. Another caution which results from the study of living forms, is that multitudes of these creatures are frequently found to develop in tanks and ponds which have been dry for more than half of the year. It is thus not unlikely that pools of fresh water, temporarily formed on a flat seashore, may have been inhabited by freshwater forms of Ostracoda destined to be quickly buried by the first wind drift of sand at the return of high tides.

Thus, perhaps, the most satisfactory palæontological indications are of a negative type. For example, the absence of marine forms from a number of samples of a deposit containing freshwater forms show it to be definitely of a freshwater origin, for, as indicated above, inland organisms may have their remains carried to find a resting place with marine deposits, but the reverse process is so unlikely as to be practically negligible.

III. Classification of Ostracoda.

Great difficulty has been experienced in arriving at a satisfactory classification of fossils of this order. This is due not only to the fact that the remains are of so minute and simple a character, but also that correlation with existing forms is rendered the more difficult as the classification of living Ostracoda is based on anatomical modifications, the shell being scarcely considered, and so we find several distinct genera with shells having essentially the same outline and surface characters. The classification of present day forms is based upon differences with respect to arrangement and character of organs of sense, mastication, locomotion, and aeration, whilst in fossil forms we can only consider the shape and structure of the carapace valves and classify on minute distinctions of hingement, overlap, muscle-spot (so-called "lucid-spot"), and ornament. Whilst the palæontologist's classification is, therefore, liable to grave misassociation, it should be remembered that the results of his efforts may be the best obtainable with the criteria available to him. Bassler refers to this difficulty in connexion with the form *Bythocypris cylindrica* of Middle and Upper Ordovician age. He

points out that whilst it is closely differentiated from associated *Cypridae*, yet the name possibly included a number of distinct species, whilst in outline and general structure its shell can be duplicated in several genera of living forms.

Before proceeding to discuss the classification adopted by present day Palæontologists it will be necessary to make a brief survey of the history of the study of the animals comprising the Order under consideration.

The Order Ostracoda was first established in 1801 by Latrielle, who, in his *Historie Naturelle Generale et particulière des Crustacea*, divided the great class Crustacea into two sub-classes, the Entomostraca and Malacostraca, the Ostracoda being included in the former. Various writers dealt with the classification of Entomostraca during the following half century, and by 1853 W. Baird was able to give the general description of an Ostracod which from his time onwards has served as the basis of recognition of members of the Order. His summarized description is as follows : " Body enclosed entirely in a covering of two valves resembling a bivalve shell. Posterior jaws branchiferous. No internal ovary. Feet, two or three pairs, adapted for progressive motion."

Thus by the time Rupert Jones commenced his long and careful study of fossil Entomostraca, the Order Ostracoda had been definitely defined and placed by students of living forms, and Palæontologists followed the system of classification so established wherever possible, and extended it only when such additions were found to be absolutely necessary. Jones himself kept closely to Dana's general classification and frequently refers to the works of G. S. Brady, who, in conjunction with A. M. Norman, published a detailed classification of the Ostracoda in 1889.

The latest systematic classification available to palæontologists is that due to Dr. R. S. Bassler and is published in the 1913 edition of Zittel's *Text-book of Palæontology*. Here we find the subclass Eucrustacea divided into five super-orders, of which the Ostracoda form the third, the Ostracoda themselves being divided into nine families. It is important to notice that the term Phyllopoda does not appear in this latest classification, the equivalents to Phyllopoda in the old sense finding their places in three of the orders included in the super-order Branchiopoda.

We have noticed above the manner in which Baird described the living ostracod, and will now briefly summarize the characteristics of an ostracod from the view-point of a palæontologist.

1. The valves are more or less oblong in outline.
2. They are longer from anterior to posterior extremity than from the superior (dorsal) to the inferior (ventral) margin.
3. They are rarely equilateral.
4. They vary considerably in the depth of their internal cavity, sometimes being hemispherical in section and sometimes presenting but an exceedingly shallow cavity.

5. The carapace is always inequivalve, the left valve being usually greater than the right.

6. The margin of the larger valve has a more or less distinct groove or rabbet for the reception of the edge of the opposite valve.

7. The mode in which the valves are attached at the dorsal borders vary from a simple groove and ridge to a more or less complicated hinge provided with teeth.

8. In the centre of each of the valves of *Cypris*, *Candona*, and *Bairdia* in the recent state, a patch of lucid spots is found, varying in size and pattern. Some fossil species (e.g. *Bairdia*) show traces of these, but they are entirely absent in others (e.g. *Cytherella*).

9. A small tubercle peculiar to *Cytherella* constantly presents itself near the centre of the inside of each of the valves of members of this family. There is no corresponding pit in the external surface.

10. In the genus *Cytheris* there is a large external tubercle on the central line of the anterior third of each valve, having a corresponding internal circular pit.

11. The exterior of the carapace valves of Ostracoda vary from a perfectly smooth convexity to a flat or irregular surface, variously ridged, tuberculated, granulated, spined, reticulated, or pitted. It is obvious that the smooth forms present great difficulty in classification, the hingements alone offering a guide for the determination of genera. On the other hand, the diversity of surface pattern on the valves of the *Beyrichiidae* of Palæozoic age and of *Cytheridae* of Mesozoic to recent times lead to accuracy of specific discrimination.

IV. Ostracoda found in the Purbeck Beds of the Vale of Aylesbury.

Much work has been done by Rupert Jones and others on Ostracoda from rocks of all ages, and a general survey of the work dealing therewith has been compiled. In the present article, however, we will confine our attention to the examination of work on Purbeck Ostracoda and show their use in the classification of the rocks of Purbeck Age in the Vale of Aylesbury.

The Purbeck rocks of this district were described by Fitton in 1836, and more recently in the Geological Survey Memoir on the Jurassic Rocks of Britain, and in several papers by Dr. A. Morley Davies. They are also referred to by Jukes-Browne and other writers. The exposures which have been examined for the purpose of the present paper are those described by Dr. Morley Davies in his paper entitled "Contributions to the Geology of the Thames Valley", in the section dealing with Purbeck Beds. Since the above paper was written, many of the pits have ceased to be worked, and consequently the exposures have become overgrown and lost. Other sections, in the course of working through rocks like the Purbecks, which undergo rapid lateral changes, cease to be recognizable from the former descrip-

tions, whilst in one or two instances entirely new workings have been found. The writer has visited the district on several occasions between Easter, 1921, and the date of this account, and the results referred to at the end of the paper are those obtained by the washing of samples which have been systematically collected during these visits.

In his paper on the Ostracoda of the Purbeck Formation, Jones gives a catalogue of definite localities and horizons in the Purbeck Rocks with the genera and species of Ostracoda found therein, and from this he draws up a Tabular Conspectus and a Synoptical List of the Purbeck and Wealden species in England. In each case we find that he proves the existence of a distinct break between the forms occurring in the Lower Purbecks and those found in the Middle and Upper.

In the above-named sections of Jones' paper, we find reference is made solely to the Lower Purbeck forms from Buckinghamshire. In the description of species, however, he mentions the typically Middle Purbeck form *Cypridae granulosa* var. *paucigranulata* as occurring at Whitchurch and figures specimens from the district. A type specimen in Jones' collection at South Kensington is labelled by him "*Cypridea fasciculata* (Forbes) Purbeck Beds, Whitchurch, Bucks. No. 229 Fitton". The original label on the specimen has the mark of interrogation differently placed, and reads as follows: "229? Whitchurch. *C. fasciculata*. Fitton, mounted." There was evidently some doubt about this specimen, and as it appears to be the only one from Buckinghamshire in Jones' collection showing tuberculate forms (there being no place called Whitchurch elsewhere where Purbeck rocks are exposed), he was evidently not prepared to accept its origin as well determined without further evidence of such forms occurring in the district.

Dr. A. Morley Davies, however, in his account of the Purbeck Beds occurring in Buckinghamshire, refers to the finding of *Cypridae punctata* both at the Bugle Pit and at Haddenham, and this fact, Chapman agrees, points to the presence of Middle or Upper (probably Upper) Purbecks in the district. The writer of the present paper found, in 1921, at Creslow Farm, a piece of rock of similar texture to that in Jones' collection which contained Middle Purbeck forms, and has also found in several of the other exposures forms characteristic of Middle and Upper Purbeck age. It has been with the intention of definitely establishing the existence of these newer beds and their relation to the underlying Lower Purbecks that this work has been undertaken.

I record below the results obtained and the present condition of the exposures, in the order given by Dr. Morley Davies in his paper on the Geology of the Thame Valley.

1, 2, 3, 5, and 6. Exposures outside the district examined.

4. *Brill*. Several samples were taken in 1921 of marls exposed in the pits here, but no Ostracoda were found.

7. *King's Cross* (north of Haddenham). The pit described in the paper is almost completely filled in with refuse, and the ditch by Dudnall Farm has not recently been cleared, and consequently Purbeck Marl can no longer be collected from its sides. I was, however, able to obtain a sample of marl from a corner of the old pit, and obtained from it specimens of *Cypridea punctata* and *C. dunkeri*.

8 and 9. *From Cuddington to beyond Dinton.* I was unable to find any exposure of the two strips mapped here. Mr. Hollis, of the County Museum, Aylesbury, however, informed me that he had obtained Ostracoda from washings of material from a small pit about 30 yards from the road and 150 yards east of the cross roads near Ford and about a mile south of Dinton. From the samples I obtained of the marls at the top of this pit I found good specimens of *Cypridea punctata*, *C. dunkeri*, and *Cyprione bristovii*. There is thus a small outlier here containing Middle and Upper Purbeck Ostracoda, but there seems to be no trace of Lower Purbeck forms in the samples examined.

10. *Stone.* This outlier has the most satisfactory exposure of any in the district, as it is marked by the famous Bugle Pit at Hartwell. This pit is now being worked again, and the section facing eastward shows the bedding very satisfactorily. As pointed out by Dr. Morley Davies, the working back of the quarry face reveals the rapid lateral changes which the Purbecks undergo. It is interesting to note that the hard fissile marl " Pendle ", which marks the base of the Purbecks in this section, is given as 9 inches thick in the section in the G.S. Memoir (1895), as 4 inches thick by Dr. Morley Davies in his section (1909), and now shows a thickness of 10 inches. The following is the section as seen in April, 1923 :—

		ft.	in.
10.	Soil and stony clay	1	0
9.	Limestone band		10
8.	Unstratified marl. Contains limestone concretions—" race ". Upper portion greenish, lower portion white	3	9
7.	Hard white limestone	1	2
6.	Marl, slightly greenish, with calcareous concretions	1	7
5.	Sand		2½
4.	Sandy clay with band of brown clay at base		7½
3.	Shelly limestone, thin-bedded		9
2.	Black marly clay, brown at base		5
1.	Pendle		10
	U. Portland Beds.		

I have found Ostracods in beds 8, 6, 4, 3, 2, and 1, the smooth forms *Cypris purbeckensis*, *Candona bononiensis*, and *C. ansata* being present in each case except the upper 12 inches to 17 inches (varying in different parts of the section) of the unstratified marl, from which I have obtained *Cypridea punctata*, *C. dunkeri*, and *Cyprione bristovii*, typically Middle Purbeck fossils. Thus these beds are mainly of Lower Purbeck age, but pass into Middle or Upper

Purbeck age unconformably towards the top of the section. The irregularity of this dividing line is an illustration of the considerable erosion which took place amongst the Purbecks themselves.

11 and 12. *Bishopstone Area.* No pits have been dug since 1899, so far as I have been able to discover.

13. *Aylesbury.* The section in the field three-quarters of a mile from Walton along the Bishopstone footpath still shows the Purbeck beds, although the Portland Beds are now hidden. The section as now seen is as follows :—

		ft.	in.
3.	Soil		3
2.	Thin-bedded limestone		8
1.	Yellowish marl, with crumbly limestone at base	1	8

I took samples from each bed and found Ostracods in both the marl and the limestone. On examination they proved to be *Cythere transiens* and *C. retirugata* associated with *Candona ansata*. The presence of these marine forms in the district are interesting as showing the change from marine conditions of Portlandian times to the freshwater Purbeckian conditions must have been gradual. Freshwater and marine Ostracoda and Foraminifera from the Purbecks are also recorded from the King's Cross section at Haddenham, and a similar mingling is also recorded in the topmost beds of the Portland Series.

14. *Coney Hill.* The lime-kilns have been closed down for a long time and the pit has been filled in and ploughed over. I endeavoured to collect samples from the edge, but they proved to be entirely unsatisfactory.

15. *Quainton Hill.* The exposures here are unsatisfactory and are mostly overgrown. I obtained two samples of marl, however, from a small pit on the north of the hill, and from them obtained specimens of *Candona ansata* and *Cythere transiens*. I also found (not in situ) a piece of hard limestone with shells and Ostracoda (*Candona ansata*) making it almost oolitic in appearance. This limestone is very similar to that found at the top of the section along the Bishopstone path, in Bed 3 at the Bugle Pit, in the " Pendle " at Oving, and at the pit near Dunton.

16. *Oving.* The pits in the market-gardens between the villages of Oving and Whitchurch give another very interesting example of the lateral variation of the Purbecks. Much material has been removed during the past thirty years from the pit 100 yards south of the North Marston road, and the present section is probably 150 yards N.E. of the original. As described in the G.S. Mem. 8 ft. 9 in. of Purbeck Beds are present. Dr. Morley Davies in 1897 records from a neighbouring pit 6 ft. 9½ in. of Purbeck covered by 2 ft. of Lower Greensand, this latter probably representing the upper 2 ft. described as Purbeck in the Survey section. The present section is as follows :—

		ft.	in.
13.	Soil		6
12.	Brown clay (calcareous band at base)	1	6
11.	" Cornstone rubble "	1	6
10.	Bluish clay darkening to black	1	6
9.	Clay and sand	1	0
8.	" Cornstone "		6
7.	Greenish marl		8
6.	" Greenstone "		6
5.	" Brockly sandstone "		2
4.	Green sandy clay	2	0
3.	Shelly band of clay		2½
2.	" Pendle "		8
1.	Shelly band of clay		6

U. Portland Limestones.

The terms " Cornstone ", " Pendle ", etc. are those used by the quarrymen—their " Pendle " consisting of a rock with grey limestone bands alternating with shelly bands containing Ostracods. These terms are also recorded by Fitton, who describes the Pendle as " soft fissile limestone, which includes worn rounded particles of stone, which gives to the whole the aspect of oolite ". This latter feature of the " Pendle " here is not noted in the definite band of hard fissile marl so-called at Hartwell, but the oolitic appearance of certain Purbeck rocks in the district has already been noted. Ostracods teem in the bed above the " Pendle ", and were also found in washings of the 2 feet of sandy clay, and from the greenish marl above. I obtained none from the higher beds. The predominating form found was *Candona ansata*.

The washings from several samples taken from the sides of ditches around Whitchurch yielded no results, but from the small disused quarry near Creslow Farm I obtained *Cypris purbeckensis* and *Candona ansata* from the marls, and *Cypridea punctata* from a limestone similar in texture to that in Jones' collection at South Kensington.

17 and 18. *Weedon, and Warren House Farm, near Stewkley.* In a small pit near a farm at the west of Dunton I found a thin bedded limestone rich in the form *Candona ansata*, and a careful examination of the section at Warren House Farm showed about 2 feet of Purbeck Marls over 10 feet of Portland limestone overlying the Portland Sands with a marked unconformity. The Purbeck Marls have yielded *Cypris purbeckensis* and *Candona ansata*. I was unable to locate any exposure at Weedon.

Summarizing the above results, a careful study of the Ostracoda found in these Purbeck rocks leads us to the following conclusions :—

1. The presence of such Middle and Upper Purbeck forms as *Cypridea punctata*, *C. dunkeri*, *C. granulosa*, and *Cyprione bristovii*, unassociated with Lower Purbeck forms, in the upper part of the unstratified marls at the Bugle Pit, at Haddenham, near Ford, and at Creslow Farm near Whitchurch, proves the presence of Middle or Upper Purbeck Beds (probably both) in the district.

2. The gritty limestone, almost oolite in appearance, found in several of the pits in the district and containing the same form *Candona ansata* was evidently deposited under the same conditions throughout the area during Lower Purbeck times.

3. The mixture of freshwater and marine Ostracods recorded by Dr. A. Morley Davies from the sections on the Walton–Bishopstone footpath and at King's Cross near Haddenham indicates the gradual transition from marine to freshwater conditions.

The above results are obtained entirely from the evidence provided by the remains of Ostracoda, and there is reason to believe that the further study of the remains of these minute organisms will lead to their being of value for the determination of the precise age and conditions of deposition of rocks lacking other distinctive characteristics.

REVIEWS.

PLATINUM IN THE WATERBERG DISTRICT. By Dr. P. A. WAGNER and T. G. TREVOR. The South African Journal of Industries, Vol. VI, No. 12. December, 1923. Pretoria.

THIS paper gives an account of the discovery of platinum on Welgevonden 1772 earlier in the year 1923, a description of the occurrences on that and the neighbouring farms about 10 miles west of Naboomspruit Station, and a discussion of the economic prospects of the deposits. The geology of the area is shown in the south-west corner of Sheet 7 (Potgietersrust) of the Geological Map of the Transvaal, and Plate X of the Ann. Rep. Geol. Surv. Tvl. for 1909.

The platinum is found in quartz reefs occupying faults of post-Karroo age in the felsites and felsite tuffs (so-called Lower Waterberg felsites). That the faulting was continued for a considerable period is proved by the brecciation of the earlier formed vein-stuff; the post-Karroo date of the faulting is proved by the fact that the main lode cuts off the late-Karroo Bushveld sandstone, which at places forms the hanging-wall. In Sheet 7 of the Geological Map a fault on Rietfontein 3 is indicated to be of post-Karroo age, and this is one of the faults on which platinum is found.

Dr. Wagner has made out the following history of the materials filling the veins :—

First stage.	Opening up of fissures in felsite and Bushveld sandstone as a result of crustal disturbance.
	Deposition of quartz, specularite, platinum, pyrite, and subordinate amounts of sericite.
	First period of brecciation.
Second stage.	Deposition of quartz, platinum, sericite, specularite, fine-grained hæmatite, and, in places, considerable amounts of the mineral from which the chromiferous chlorite was derived.
	Further fissuring and brecciation.

Third stage. Deposition of white quartz apparently free from metallic minerals.

Further fissuring.

Fourth stage. Deposition of white quartz apparently free from metallic minerals.

The platinum is obviously chiefly a primary constituent of early date, and is intergrown with specularite, and it is also intimately associated with quartz and secondary iron oxide, presumably derived from the oxidation of pyrite. Dr. Wagner concludes that the deposits were formed during a period of crustal disturbance by vapours and solutions emanating from a concealed body of igneous rock, probably of a highly siliceous nature, situated at no great depth. Hot springs on the fault-lines may represent the final stage of hydrothermal activity.

The main lode has been proved to contain platinum for several thousand feet over a range in altitude of 150 feet, and its width is from 6 to 28 feet. A branch lode has been traced over a distance of 1,200 feet with a width up to 5½ feet. The greatest depth yet reached in a winze is 36 feet. The distribution of the platinum metals is erratic; samples from widths of from 21 to 72 inches range from a trace to 1,019·5 dwt. per short ton.

While no very great output is anticipated, the prospects are regarded as favourable.

With the platinum are associated palladium and iridium; an assay quoted gives, per short ton of ore, platinum 237·2 dwt., palladium 108·6 dwt., and iridium 39·2 dwt.

On Marine Triassic Shells from Singapore. By R. B. Newton. *Ann. Mag. N.H.* [9], xii. 1923. pp. 300–21, pl. ix.

THE discovery of a Triassic fauna in the Island of Singapore by the Government Geologist, Mr. J. B. Scrivenor, and the report thereon by Mr. R. Bullen Newton, form important contributions to our limited knowledge of the palæontology of that region. The fossils consist chiefly of Pelecypod Molluscan impressions in a somewhat friable sandstone, among which are remains of *Myophoria*, a genus characteristic of the Triassic period. The facies of this fauna is stated to be "distinctly that belonging to the St. Cassian beds of the Austrian Tyrol; on the other hand, two or three forms suggest an origin among the older deposits of the Muschelkalk, whereas others exhibit a later, or Rhætic character". As a tentative measure, therefore, the fauna is regarded as of Upper Trias or Rhætic age.

It is considered that the Singapore beds are an extension of the Myophorian Sandstone of Pahang, which Mr. Newton described in 1900, although the two areas are somewhat widely separated.

From a distribution table of the fauna it is clearly seen that some of the species referred to extend from Europe through India, Burma, Tonkin, New Zealand, and New Caledonia.